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TRANSACTIONS

OF THE

AMERICAN CERAMIC SOCIETY

CONTAINING THE PAPERS AND DISCUSSIONS

OF THE

FOURTH ANNUAL MEETING

HELD AT

CLEVELAND, OHIO,

FEBY 10-12, 1902.

The Society is not, as an organization, responsible for the statements of fact or opinion expressed in its papers and discussions.

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FOR THE YEAR ENDING FEBRUARY, 1903.

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RAUTER, DR. GUSTAV, Charlottenberg 4, Berlin.	Engineering Chemist.
RIX, WILTON PARKER, 34 Liverpool Road, Newcastle, Staffordshire, England.	Consulting Ceramist.
ROESSLER, FRANZ. 100 William St., New York, N. Y.	Vice Pres,, and Supt., Roessler & Hasslacher.
RUSSELL, JOSEPH, 1302 Queen St., East, Toronto, Canada.	Brick Manufacturer.
SHAW, FRANCES D., 927 Edgewood Ave., Trenton, N. J.	Shaw Vitreous Enamel Co.

SIMPKINS, RALPH, St. Louis, Mo.	Manager Union Press Brick Wks.
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YATES, ALFRED, Johnsonburg, Pa.	Johnsonburg Vitrified Brick Co.

RULES.

OBJECTS.

The objects of the American Ceramic Society are to promote the arts and sciences connected with Ceramics by means of meetings for social intercourse, for the reading and discussion of professional papers, and for the publication of professional literature.

MEMBERSHIP.

The Society shall consist of Honorary Members, Members and Associates.

Honorary Members must be persons of acknowledged professional eminence, and shall not exceed five in number.

Members shall be persons competent to fill responsible positions in Ceramics and have suitable qualifications.

Associates shall include persons interested in Ceramics and the allied arts.

Honorary Members shall be proposed by at least five Members, approved by the Council, and receive at least 90 per cent. of the votes cast by letter ballot at the annual meeting.

Members and Associates shall be proposed by at least three Members or Associates, approved by the Council, and receive at least 75 per cent. of the votes cast by letter ballot. A candidate for admission must make application on a form prepared by the Council which shall contain a written statement of his age, professional experience, and that he will, if elected, conform to the laws, rules, and requirements of the Society.

All Honorary Members, Members and Associates shall be equally entitled to the privileges of membership, except that only Members shall be entitled to hold office and to vote. Applicants for a change in grade of membership shall conform to the requirements of a new applicant.

Any person can be stricken from the membership of the Society on the request of five or more Members, on the recommendation of a majority of the Council, if he fails to resign on the advice of the Council. Such person, however, shall first be notified of the charges against him, and be given a reasonable time to appear before the Council, or present a written defense, before final action is taken by the Council.

DUES.

Honorary Members shall be exempt from all dues.

The initiation fee of Members shall be ten dollars, and of Associates five dollars, which if not paid within six months after election, will render the election void.

The annual dues for Members will be fixed by the Council, but shall not exceed five dollars per year.

The annual dues for Associates will be fixed by the Council, but shall not exceed four dollars per year.

Any Member or Associate in arrears for over one year may be suspended from membership by the Council until such arrears are paid.

OFFICERS.

The affairs of the Society shall be managed by a Council, consisting of a President, Vice President, Secretary, Treasurer, and three Managers, who shall be elected from the members at the annual meeting, and hold office until the adjournment of the meeting at which their successors are elected.

The President, Vice President, Secretary and Treasurer shall be elected for one year, and the Managers for three years; and no President, Vice President, or Manager shall be eligible for immediate re-election to the same office.

The duties of all officers shall be such as usually appertain to their offices, or may be delegated to them by the Council or the Society; and the Council may at its discretion require bonds to be furnished by the Treasurer.

Vacancies in any office shall be filled by appointment by the Council, but the new incumbent shall not thereby be rendered ineligible to re-election at the next annual meeting to the same office. On the failure of any officer to execute his duties within a reasonable time, the Council, after duly warning such officer, may declare the office vacant, and appoint a new incumbent.

A majority of the Council shall constitute a quorum; but the Council shall be permitted to carry on such business as it may desire by letter.

ELECTIONS.

At the annual meeting, a nominating committee of five Members, not officers of the Society, shall be appointed, and this committee shall send the names of nominees to the Secretary at least 60 days before the annual meeting, who shall immediately forward the same to the Members. Any other five members may also present the names of any candidates to the Secretary, provided it is done at least 30 days befor the annual meeting. The names of all candidates, provided their assent has been obtained, shall be placed on the ballot without distinction as to nomination by the regular or an independent nominating committee, which shall be mailed to every member, not in arrears, at least 20 days before the annual meeting.

The ballot shall be inclosed in an inner blank envelope, and the outer envelope shall be endorsed by the voter, and mailed to the Secretary for collection. The blank envelopes shall be opened by three Scrutineers appointed by the Chair at the annual meeting, who will report the result of the election. A plurality of the votes cast shall elect.

MEETINGS.

The annual meetings shall take place at such time and place as the Council may decide, at which time reports shall be made by the Council, Treasurer, and Scrutineers of election, and the accounts of the Treasurer audited by a committee of three appointed by the Chair.

Other meetings may be held at such times and places during the year as the Council may decide, but at least 20 days' notice shall be given of such meetings.

Seven Members shall constitute a quorum at any regular meeting, and a majority shall rule, except where otherwise specified.

The order of business at the annual meeting shall be:—

1. Reading of Minutes of last meeting.
2. Reports of the Council and Treasurer of the Society.
3. Announcement of Election of Members.
4. Announcement of Election of Officers.
5. Appointment of Nominating Committee.
6. Old Business.
7. New Business.
8. Reading of Papers.

PUBLICATIONS

The Council shall act as a Publication Committee, and decide as to what to publish. The publications of the Society shall be sent to all Members and Associates not in arrears. The Secretary will furnish each author with reprints of his papers at cost price, provided due notice is given that reprints are desired.

The Society is not, as a body, responsible for the statements or opinions expressed in its publications.

PARLIAMENTARY STANDARD.

Roberts' "Rules of Order" shall be the parliamentary standard on all points not covered by these rules.

AMENDMENTS.

These rules may be amended at any regular meeting by a two-thirds vote of a letter ballot at the subsequent annual meeting provided a written notice of such proposed change is sent to each Member at least 30 days before said annual meeting. Said proposed amendments shall be printed on the ballot for officers and counted by the same Scrutineers.

PUBLICATIONS.

The publications of the Society are as follows:

DESCRIPTION OF VOLUME.	Price to Members.	Price to Others
Vol. I. Transactions for 1899, 110 pages, bound in paper,	$ 0.50	$ 4.00
Vol. II. Transactions for 1900, 278 pages, bound in paper,	2.00	4.00
Vol. III. Transactions for 1901, 230 pages, bound in paper,	1.00	4.00
Vol. IV. Transactions for 1902, 300 pages, bound in paper,	1.50	4.00
Manual of Ceramic Calculation (contained in Vol. II as a part thereof,) 86 pages, bound in paper,	1.00	1.00
The Collected Writings of Dr. Hermann August Seger, Volume I. Contains (A) Treatises of a general scientific nature, (B) Essays relating to Brick and Terra Cotta, Earthenware and Stoneware, and Refractory Wares. Pages 552. Bound in cloth.	7.50	7.50
The Collected Writings of Dr. Hermann August Seger, Volume II. Contains (B) Essays on Whitewares and Porcelain. (C) Travels, Letters and Polemics. (D) Uncompleted works, and extracts from the archives of the Royal Porcelain Factory. Pages 590 (est). Bound in cloth.	7.50	7.50

Every member or associate receives one copy of the Transactions free for each year for which he pays dues. He is entitled to purchase copies for the years antedating his connection with the Society at the costs indicated in the first column. All others can obtain copies at the prices listed in the second column by sending order, accompanied with check, to

STANLEY G. BURT,
Care of Rookwood Pottery Co.,
CINCINNATI, OHIO.

PREFACE.

The following pages contain the papers and discussions of the Fourth Annual Meeting, held at Cleveland, Ohio, February 10th, 11th and 12th, 1902.

In addition, a new departure has been made in this volume, in publishing a number of articles and contributions which have not been read before the Society, and, in fact, were not prepared at the date of the meeting. This policy, it is hoped and believed, will be the first step towards relieving the pressure of our meetings, in which it has grown more difficult each year to hear all of the papers and discussions offered. As the Society grows in importance and influence, it will surely reach a point where only the papers of unusual general interest will be read at the meetings, and the others will be read by title and published. The progressive intricacy of the papers already presented has shown very clearly that it is only in occasional cases that masses of technical facts can be made intelligible by reading aloud, while they readily can be comprehended when put in print.

From this point of view, therefore, as well as the number and quality of papers, it seems that this is by all means the best year's work yet accomplished by the Society. In addition, it may be said that the volume would have been improved by the addition of two other articles, one of more than general interest to brickmakers, had not the time limits urgently required that this book be sent out without delay. It is expected that one or both of these articles will still be printed and distributed as a bulletin, between this date and that of the next annual meeting.

The growth of the Society has continued rapid and good. The members seem enthusiastic, and certainly gives one evidence of this fact in maintaining their connection with very few withdrawals for any cause. The continued increase in foreign membership is noted with gratification.

The announcement of the facts concerning the publications has been given a separate page in this issue.

EDWARD ORTON, JR.,
Secretary.

COLUMBUS, O., Oct. 1, 1902.

THE PROGRESS OF THE CERAMIC ART.

ADDRESS BY THE RETIRING PRESIDENT,

CHARLES F. BINNS, ALFRED, N. Y.

It is well, in any walk of life, as we pass the posts which mark our progress, to look backward and around, that we may take a broad and comprehensive view of the field we occupy. The work done by our competitors and neighbors should concern us at least to some extent and even if we clash in rivalry, we can find evidence of mutual interest and possibly help.

Progress can be measured from three widely differing standpoints: the artistic, the technical and the commercial. In most cases the final arbitrament is found in the last, for it can be said with some measure of truth, that art and science are successful in manufacture only in so far as they prove financially sound. But this not entirely true. Beautiful work is regardless of cost and no amount of money expended can of itself make an artistic product. The fact is also self-evident that artistic wares can be made at a financial sacrifice. In other words, a product may be artistic whether the manufacture pays or not, and a profitable line is not necessarily artistic.

The same is true to a less extent of technical success. To a less extent, because science is more readily controlled than art. The artistic faculty is subtle and elusive, the scientific is exact and material. But neither is scientific and technical success to be measured entirely by money. Our best research is carried on independently of financial considerations and an improvement in quality or manufacture is not necessarily a means of making money.

Commercial success, is of course, measured by the dollar. The man who can make the most profitable ware and sell the largest quantity of it is the most successful commercial man.

From these points of view then let us take a glance over the progress of the world in recent times.

It must here be noticed that in some of the most marked advances it is difficult to say whether the artistic or the technical is the more concerned. The former is the more obvious, certainly, but the latter is fully as important. The work displayed by the National manufactory of Sevres at the Paris Exposition of 1900 was the finest exhibit of hard porcelain ever shown. Technically perfect, it was artistically fine, but, of course, would be called a commercial failure. The Royal Copenhagen factory has work which is equally fine, though very different. This factory claims a new body for plates and dishes which is much lighter than the old, without any counter-balancing disadvantage. In such a matter as this, the technical, of course, overshadows the artistic, and in fact, for reasons already stated, the artistic advance is far less easily defined. Art is a matter not of a new discovery, but of a particular expression. It is, in fact, the soul of a production, while the technical is merely the frame or body.

In illustration of this, let notice be taken of the modern English wares. There is practically no technical variation in the product of half a dozen of the leading factories and yet some are more approved than others simply because of a finer artistic sense.

The minute variation, the subtle touch which may make or mar a work of art cannot be defined, nor is it to be located by any scientific method.

Of European technical advance we have little opportunity of judging as regards coarse wares, for there is practically no competition with us in the matter. In large measure, the older methods are used and the low price of labor renders the employment of modern machinery unnecessary. Hand-moulded brick are still in the lead in England and many of the lines of work would be considered antiquated even in the slowest American brickyards.

In fine terra-cotta, France takes the lead; the productions of Muller, of Paris, stand very high both in art and technique. Germany can match the work probably, but not the spirit. It is an interesting study for those concerned as

to why most German work is artistically so poor and most French so fine. Moreover, the Germans seem to be able to make more money out of their technical knowledge than the French of their art. Take for example the flood of cheap bric-a-brac with which the Germans are covering this country. One can but admire the technical excellence of the work, the composition of body and glaze and the simplicity of manufacture, while at the same time the paucity of artistic idea is most evident. These goods are sold at such trifling cost that when the sixty per cent. duty, the freight and the packing are considered, one wonders what price the manufacturer secured, to say nothing of the amount received by the wage-earner.

The production of ceramic wares in the United States is naturally of the more immediate interest to ourselves for not only are we concerned in the manufacture, but the success of our work will of necessity diminish the importation of competing wares.

Some of our manufacturers are, happily, free from the worry of foreign competition, but they will doubtless claim special and peculiar troubles. No day-worker has a monopoly of worry, but each claims to have a special heritage of it in some individual and peculiar right. The brick-maker has the field to himself—until his neighbor's territory is reached, but he has to give his product away in order to meet his pay-roll. The maker of finer wares gets a fair price, but the stores are filled with foreign importation, and so it goes.

It is probably without question that the manufacture of building material in this country is ahead of anything elsewhere. Brick of every description, common and front, glazed and enameled, fire proofing and terra-cotta, roofing tile and wall tile as well as paving brick are made here in great perfection and the lines of drain-tile, sewer-pipe and electric conduits run them very close. In fact, where the successful product depends upon an intelligent application of engineering, the American is well to the front. Here, the artistic element scarcely appears, except in the matter of terra-cotta, but the technical and mechanical skill involved is of a very high order. Mention should be made here of

the successful manufacture of porcelain baths and sinks. But a short while ago we imported all our supply of these commodities; but now, such is the advance made, we are exporting. It should perhaps be explained that "porcelain" is only a name. The body is a refractory clay which is coated with a white slip and a clear glaze, the whole being burned at one and the same time. The result is a compact, impervious ware which, if somewhat heavy, is practically everlasting.

In terra-cotta and wall-tile great advances have been made in the matter of glazes. Every prominent factory now has a full line of tints both mat and bright, many of them very beautiful. The problems involved in each case differ somewhat in that terra-cotta is glazed almost entirely upon the unburned clay, while tile being mainly dust pressed must of necessity be fired before glazing.

In the finer branches of ceramic art we are bound, if honest, to confess a certain weakness. There are many among the ranks of the connoisseurs who ask skeptically whether America can make fine pottery, and they emphasize their doubt by saying that the necessary clay is not found in the United States. We who are engaged in utilizing native clays know better, but given the material, can we make fine pottery? In reply, we point with pride to Rookwood but are asked if a solitary example demonstrates the ability of the nation. It does, provided the necessary conditions are observed. Here allow me to digress for a moment, not in defence of Rookwood—that were quite unnecessary—but in criticism and even condemnation of the shameless copyist, who imitates body, glaze and coloring and claims something just as good at one-third the price. I hold no brief for Rookwood and my criticism would be just as severe upon any copyist. He plunders the brain and thought of the master mind, he seizes upon the external features, those that can be easily and cheaply pirated. He ignores or slaughters the soul and all that makes the work really valuable, and carries out his impudent imitation only to make money. Do we not sometimes despair for the commercial morality of our people when such things are done and approved as being smart or clever. But there is a point of

satisfaction in this cruel competition: it is, that Rookwood by virtue of her superiority of resource, can move faster than the pirates, and in this is her real safety. Fine work such as this is spontaneous and exuberant, the originator soars triumphantly upward while the slow herd of copyists flounder laboriously below.

In the manufacture of household pottery there is matter both for regret and congratulation. The wares classed by the hired girl, conveniently and comprehensively, as "dishes," are produced here in large quantities, and the matter for regret is, that they are generally so devoid of artistic merit. A glance through the advertising pages of any trade journal will reveal shapes, classed as "new" which are simply a rehash of similar things and which are evidently modeled in view of the sagger and stilt. Just what will make easily, fire safely, and hold something inside while in the kiln.

Nevertheless the manufacturers may be congratulated in that the use of American materials is extending, the bugbear of crazed goods is disappearing and the works are being run at a profit. There remains, naturally, some considerable number in the ranks of the non-progressive and even of the wilfully blind. Every now and then the ceramic world is startled by the announcement that a remedy for crazing has been found, a magic solution which, added to the dipping tub will banish forever the phantom of craze while, had the discoverer only read the current technical literature, he would long ago have found that magic is quite unnecessary and that science has already exorcised the demon and only an imaginary ghost remains to those who keep their eyes shut.

The greatest advance of recent years is in the matter of hotel china. This is a distinct outgrowth of American enterprise and skill. There had long been a dissatisfaction with French china. The ware was brittle and took long to replace. When, therefore, the American potter came forward with a tough ware — not an imitation, but a native success— he was welcomed by the hotels using large quantities of table goods. By one factory after another the problem has

been taken up and solved. Harder fires gave stronger wares, better clays gave better texture and color, improved methods gave better glazes until the American hotel china in technical quality and fitness for its purpose stands unrivalled in the world.

Once more it is laid upon me to raise the lament that we do not make fine porcelain. Hotel china, Belleek, Faience, each has its place but the lover of American ceramics cannot handle fine specimens of European wares without a pang of regret. Why is the like not made here? We have the finest clays, the best workmen, the greatest wealth. Why not then the finest porcelain? Will no patriotic manufacturer take up such a work *con amore*? Will no enthusiastic millionaire endow a small factory to remove this blot from our industrial and artistic fame? Surely, when millions are spent in collecting specimens manufactured long ago in other lands there should be a possibility of the artistic and technical skill of our own people being fostered and encouraged ro this end. Be it remembered that fine wares cannot be made for money alone, that profit must not be thought of—at least in the beginning—if a world-wide reputation is to be made, it will be apparent why our manufactures have not touched the question. For the same reason it must be evident that if we are to make porcelain which will be equal to Rookwood faience, which will compare with Copenhagen and with Sevres, it must be beneath the roof of some beneficient capitalist who will draw his profits from the pride of possession.

The members of this society may congratulate themselves that their share in the advance has not been immaterial but still more upon the fact that when a call to greater advance comes they are ready.

Much of the work has been done in the face of cavil and misrepresentation. The incredulous smile of the "practical man" still lingers around us, and there is much opposition to be lived down but the day will come, and it is not far distant, when the graduates of our schools will be sought by every plant in the country and our industry will rise to heights that are as yet unexplored.

NOTES ON THE GRINDING OF MATERIALS USED IN EARTHENWARE BODIES.

BY

ERNEST MAYER, Beaver Falls, Pa.

The question of the degree of fineness to which the flint and feldspar used in pottery bodies shall be ground is one that does not receive in the United States the attention and care bestowed on it by European potters. It is my intention, as far as I am able, to awaken a greater interest in this subject, and show by trials submitted for your inspection, that the statements made can be amply verified.

As to the system of grinding in Europe, more particularly in England, where I gained my practical experience, let me point out a fact not generally understood, viz: That dry grinding is practically unknown—(remember, I speak of England). Although the system of dry grinding has been systematically tested and a considerable sum of money spent to make a success of it, it has been abandoned as impracticable, and they still continue to grind their materials by the wet process as of old.

Before proceeding further in my subject, it may be well for me to state my reason for bringing this subject up at all and explain the reason why I lay such stress on the matter of fine grinding. I recollect of no meeting held by our Society where this subject has not been brought up, and at several of them I have ~~have~~ had considerable to say, and when the subject was talked over in one of our discussions last year, I made the assertion that it is one of the most important enconomic problems in our business, as I hope to show before my paper is concluded.

It has been to me, till recently, an unsolved enigma, why English potters can fire a dense body, with a clear ring and a close fracture, at a temperature of Seger cone 5, whereas, our body at a temperature of cone 8 down and 9 begin-

ning to move, will not make so dense a ware, or so clean a fracture, while we have a body containing, as shown by chemical analysis, a percentage of alkali and fluxing materials, at least 35 per cent. greater than theirs. I don't wish to be misunderstood and have it supposed for an instant that I am comparing American and English ware to the detriment of the former, because the fact is now appreciated and has been for some time that we are getting just as good a price as they do in open competition.

What would it mean to us today, if we could bring our biscuit heat down to cone 5 instead of going to the excessive temperature we do?

First: A very important item, saving of fuel.

Second: Saving in saggars, on account of less heat employed, and the fact of being able to use very much cheaper clays than the very high priced ones we now have to buy in order to get sufficient refractoryness.

Third: The easier regulating and more even firing of the kilns at the lower temperatures.

This third reason is unquestionably a debatable one and one that I don't consider so important as the first two, as, from my point of view, there can be no possible question raised concerning these. I also claim that the finer grinding of our materials will not only help in reference to fuel and saggers and firing, but it will stop a large quantity of so-called mishaps that occur to us all without any apparent reason; mysteries that happen in all our potteries without any cause being discovered, and which disappear as mysteriously as they came.

Who is there here that has not run up against one of the following circumstances: A manager is called into the clay shops to see a quantity of ware cracked in the moulds, a very excessive amount, whereas the day before, and probably for months previous, the percentage of cracked ware is normal. He knows that he has got in no new material; all the clays, flint and feldspar have been taken from the same bins, and no error has been made in mixing. The next day, the trouble which existed practically with nearly all the clay, suddenly disappears and everything goes on as usual. What

has happened is probably this: The slip has been made too thin by the accidental running of too much water into the blunger. During the night the body has settled down in the bottom of the tanks into a hard mass, and if the slip pumps are started at the same time as the other machinery, nobody knows what is being pumped into the presses. It may be principally flint, or may be no flint, but whatever it is, it is not the body as originally mixed. The trouble does not end with your having some cracked ware in the clay shops. That which does not crack goes forward and fetches up in the glost warehouse as shivered or crazed.

It may be said that this is a very far-fetched case and not liable to happen, and if it did happen, can easily be remedied. In answer, let me ask: Is it remedied? Is it a common practice to start the agitators at least one hour before the pumps start?

Now the question is, will finer grinding help this difficulty? Most certainly it will, and the demonstrations I propose to make will convince the most skeptical.

I have here samples of two bodies made as under:

No. 1547—	American ground flint	106
	Feldspar, regular ground	42
	China clay	104
	Ball clay	59

No. 1548—	English ground flint	106
	Feldspar	42
	China clay	104
	Ball clay	59

You will take particular notice of the fact that these two bodies were fired together in the same saggar and the series of cones 7, 8 and 9 were fired with them and that cone 7 is only slightly turned, and this is not a proper temperature at which sound biscuit earthenware can be made under our present system, yet you will find on comparison, that while body No. 1547 is very absorbent, No. 1548 is not nearly so much so. In fact, No. 1548 would pass as fair biscuit ware. Again, notice body No. 1547 is cut easily with the point of a knife, while No. 1548 will turn the edge of a knife, and lastly, as might be expected, there is a distinct differ-

ence in shrinkage between the two, No. 1548 being the smaller of the two.

These differences I ascribe to the fineness of grain to which the English flint has been ground. I had hoped to show in a very conclusive and positive manner by means of Schoene's elutriating apparatus exactly what this difference in grinding meant by making a series of determinations, and from their averages, give the quantity that passed over at the various current velocities indicated by the pietzometer readings.

Before giving you the results of my investigations by this instrument, I would like to state that it is comparatively new to me, and I hesitate somewhat in offering the determinations as evidence, because on the face of it I am in error, simply from the fact that I don't account for the 5 grains of flint with which I started in each washing test.

I will now give the result of my determinations:

	American Ground Flint.	English Ground Flint.
@ 1.25 Pietzometer,	.4576	.7378
@ 5.10 "	.4378	.4066
@ 17.50 "	.3027	1.8878
@ 60.00 "	2.3558	1.2034
Balance left,	.7298	.3050
	4.2837	4.5408
Decantation	.1326	.0889
Unaccounted for	.5837	.3705
	5.0000	5.0000

If I interpret these figures correctly, the showing is in favor of the English flint, on account of the great differences in regard to the quantity passing over at the lower velocities. The American ground flint showed nearly twice as much passing over at the 60 cm. pressure as the English flint did. The difficulty I had to encounter in these investigations was this: That although I followed the best instructions I had as to the method of preparing the material, I was unable to get a clear liquid at the lowest reading, viz: 1.25 cm. In some of the trials I made, I allowed the mixture of the flint and water to stand two days, and after that time there

was a distinct milkiness, which no filter paper (at least in my hands) would arrest.

I mention this fact, which was identical in both varieties of flint, because I feel very sure that the items "Decantation" and "Unaccounted for" belong to the 1.25 cm. reading. I will further explain that the item "Decantation" was that portion of the liquid that still appeared as a cloudy fluid and *was arrested by a filter paper* and was weighed.

In short, if the figures of the test are rearranged as I think they really belong, we should have:

Description of Sediment.	English Flint. Percents.	American Flint. Percents.
Finest sizes, lost in process	7.41	11.67
Too fine to settle, but was caught on filter paper	1.78	2.65
At 1.25 cm. Pietzometer, slowest measured speed. Particles immensely fine	14.75	9.15
At 5.1 cm. Pietzometer; still exceedingly fine	8.13	8.76
At 17.50 cm. Pietzometer; still very fine	37.75	6.05
At 60 cm. Pietzometer. Particles relatively coarse, though still not to be distinguished clearly by the unaided eye	24.07	47.12
Coarsest particles, left after all others had floated away. Grains clearly visible to the eye	6.10	14.59
Totals	99.99	99.99
Total sediments down to and including the 17.50. cm. sediment	69.82	38.28
Total sediments, coarser than the 17.50 cm. sediment	30.17	61.71

In connection with the grinding of materials, I have so far only touched on the infusible portion, viz., the flint, but I now want to call your attention to quite as important a point, viz., the feldspar.

Some years ago, I made the experiment I have here repeated—and offer for inspection—but the marked difference in fusion as it is affected by the grinding is not nearly so

pronounced in this experiment as the one made sometime ago, because the experiment was not made under the same conditions.

The experiment consisted in grinding a batch of feldspar in a pan and removing from the pan at the end of each hour a portion of the feldspar slip. This slip was hardened on plaster and made up into cones, similar in size and shape to the Seger cones. These cones were then placed on a slab of white ware body, together with Seger cones Nos. 7, 8 and 9, and were fired in a regular biscuit burn. The feldspar taken direct from the bin gave a cone which stood up throughout the test without fusing. The cone representing one hour's grinding showed a distinct improvement in fusibility, and so on with each hour's grinding until the fourth, after which additional grinding seemed to produce but little effect. In the first experiment I made, I ground the trial on a pan having an area of 28 square feet, and this was made on a small color pan of 1¾ feet area, and on account of the difference between the weights of the runners in the respective pans, the degrees of fusion were not so clearly shown in one case as the other. Still, it will be seen that the sample marked "O," which is ordinary feldspar, taken from the bins, is very different from that marked 1, 2 and 3, but after it passes the fourth hour the change is apparently imperceptible, even up to the eight hours' grinding. On the rear in second row of cones on the trial slab you will notice cones 7, 8 and 9, cone 7 being down

Having stated my case, let us see whether anything practical can come from this paper. Is it of sufficient importance for this society to appoint a committee to devise a method for testing flint and feldspar? I refer, of course, to a mechanical test, which we might call the "American Ceramic Society's" test? Let us first of all know what we want, and then when we buy material, ask the seller if he will guarantee it to stand the society's test.

One half of all the earthenware we turn out is composed of flint and feldspar, and sometimes we hear of a certain firm of flint and feldspar grinders who grind very fine, but in nine cases out of ten the only question that is asked is will

it pass a 12*s* lawn well. Because it passes a 12*s* lawn, does not necessarily fit it for an earthenware body.

We may, if the Society desires to go into the question at all, make it a lawn test if that is the best, but, if they do, make it fine enough and say that a certain per cent. must pass the standard lawn they adopt.

To grind finer means more expense, but that need not prohibit its use. Suppose we do make a test, and the flint grinder says I will grind it as you wish but it will cost you so much more, then it is up to the user to say whether he wants it or not.

If any move is made in this direction, it must be made by the ceramic chemist, for it is eminently in his province.

DISCUSSION.

Mr. Stanley G. Burt: Mr. Mayer treats there a subject which is a hobby of mine. I have felt all along that the subject of grinding was of greatest importance; that the fineness of grain was the great keynote to many troubles, and many will remember that, as stated in my paper, that my results were equivalent to his. I did not go as far as he goes in making the suggestion of a committee to investigate the subject and set up a standard. I think the idea is very good; but in all my conversations with grinders, they say it is absolutely impossible to do that, because the additional cost necessary to get additional fineness of grind will not be stood by the American consumer. I could not give the figures, but flint furnished to pass a No. 14 lawn would cost considerable more than double if put into condition to pass a No. 16 lawn. It would mean considerable more than double the work and would add considerably to the cost. I think anything which might be accomplished in that line would be a great gain. While we may not be able to set up a standard, to say that it shall pass a certain lawn, we could insist on uniformity. I think it would be a good thing for the potters to agree among themselves upon a standard, say to pass a No. 14 lawn, then insist to the dealers that shipments must pass that lawn. I have found a number in my experience that would not begin to pass a No. 14 lawn. It seems to me

feasible to adopt a minimum standard, but I doubt if we could push it to a No. 16. But we could insist on the material passing a No. 14 lawn. I think this is one of the most important matters — fineness of grain — but I do not know whether there should be more committee work.

Mr. W. D. Gates: I move that a committee be appointed, of which Mr. Mayer shall be chairman, and Mr. Burt and Professor Orton other members, to take this matter in hand and make report.

I think we will always find that the buyer is the "doctor." If he insists on a thing, the people will "get busy" and get it, if his demands are anywhere within the range of possibility. We occasionally run across people ourselves who want things which we say at first are impossible, but if they insist on them, we have to go to work and try to make them. If fine grinding is done in England, we can certainly do it in this country.

Professor Orton, Jr.: I approve of the idea of this society trying to define something like a standard of fineness. I think it is an excellent idea. Whether we can enforce what we think is right and proper in the matter is another question altogether. I think what we do accomplish in that direction will be more in the way of giving each buyer arguments with which to hold up his end of the controversy, when it comes to dealing with the spar miller or flint miller, than in any other way. This society has no standing in the commercial world, and no lever by which it can bring into line either the spar or flint miller. Both are influenced by commercial considerations. It seems to me, therefore, that our attitude can be simply advisory. We set up the facts, but it be the buyer who enforces our findings with the spar and flint millers.

I am exceedingly pleased with the facts which Mr. Mayer has brought out. I have had a little experience with that Schœne apparatus myself, and if Mr. Mayer was here I could reassure him as to the quality of the results, which he feels so uncertain in presenting. The apparatus is not a perfect one, and I never yet saw a man who could take five grams of material, wash it into a number of grades of

fineness with the Schœne apparatus, and get back all with which he started. It seems physically impossible to save all the material; and I think Mr. Mayer has made, on the whole, a very creditable showing in his first attempt, and his results are similar to what I have myself secured and seen others get. He has proved his point by the use of this apparatus. There is no kind of question about that. The respective valuations of this one line (indicating on the chart) "2.3558 against 1.2034" show that. The American flint shows twice as much as the other. The whole experiment shows the great difference in physical characteristics. It seems to me that what a committee appointed by this society should do, is not to say what the spar miller should produce, or what the dealer should buy, but what the size of grain should be in order to accomplish certain results. Then let the commercial question settle itself.

For instance, Mr. Mayer says that beyond a certain limit there is no use for further grinding. Wouldn't it be well for this proposed committee to say how fine it is necessary to have material ground in order to produce certain results? Mr. Bleininger read a paper last year, touching on cement manufacture, in which he gave carefully prepared data on the sizes of grain of flint and spar. He illustrated the effect which the size of grain had on the decomposition of the material by lime, and clearly showed that either flint or spar above a certain size was well-nigh useless in cement, being simply inert material at the close of the process. But below a certain size it was chemically valuable, because, under standard conditions, it would be converted into soluble matter, and form a part of the cement. It was very clearly shown in that problem what the limiting conditions in cement work are. It seems to me, if we can do the same for the use of flint and spar and other insoluble fluxes in use in this country, and show that good results can be gotten from flint and spar of certain sizes, and recommend that they be considered as standard, then the whole situation will be cleared up, and anybody who desires to avail himself of our information or our work, can do so. It seems to me this is the only basis on which we can stand.

In regard to the constitution of the committee, I believe I was named as one, but I suggest that this would be a bad appointment, because I am not a great user of such materials and have little influence commercially. There are others here, who purchase thousands of dollars' worth a year, and other things being equal, they would have more influence.

Mr. Edward C. Stover: In looking over Dr. Seger's work on the question of grinding, find he touches that point, in giving the methods of changing the coefficient of expansion. In setting forth the ways of making the change, among other things, he says to grind the flint or spar finer. I took the matter up with a local spar grinder, and asked what the extra expense would be of making a finer grind. He said he had experimented along that line, and if I remember, he said that they ground an ordinary charge in a common ball mill, three or four hours longer, after the time when they considered it ready to deliver to the potter. He said in dry grinding, the difference in fineness of the material was so slight after double time, that to get such results as I wanted, would make the expense greatly more than any potter would pay. That came into my mind when Mr. Mayer's paper was read. I presume his American flint was dry ground, and the English flint wet ground. In short, he is comparing dry grinding with wet grinding, As I understand it, English material is delivered in the slop state, while here we get it dry.

Professor Charles F. Binns: I am very much struck with the calm way in which this work is handed over to a committee, without much idea of the immensity of the problems involved. It would probably take two or three investigators a year's time to standardize tests, in order to find out what they were really driving at.

The state of affairs in England is that the bulk of the larger producers grind their own material. Every large factory, I may say, without exception, has its own mill. The smaller ones buy the material ready ground in the slop state for the most part. This involves wet mixing instead of dry, which is not in accordance with the American idea of speed. The manufacturer cannot get out anything like as many tons in the same time by the wet process.

In England the materials are prepared and lawned in the slop state. The lawns are sixteen and eighteen for common wares, and each material is lawned before mixing. In some cases ball-clay is put through three decks of lawns. Under such conditions you would have to reconstruct every plant in the country and you will not find one potter in ten who would consider the matter even if you put to him the inducement that he can make better ware at a lower cost. You ask the Belleek manufacturer what is the secret of success in the manufacture of Belleek, and he will say that it is fine grinding. The material is ground until it is an impalpable powder; when tested between the thumb nails there is no grit. In a factory I was once connected with, there was a time when we kept a man all the time chipping spar, rejecting the brown parts of the spar. The question of grinding was raised and we made a test. A bucket full of the chips were put into the ball mill and ground perhaps six hours, and the Belleek made from it was every bit as good as that made from the selected spar, showing that the whole problem lay in the grinding.

I do not believe it is possible, with the present equipment of our flint mills, to give finer material. The cylinders are wood-lined, and the flint and spar are ground dry. If some miller had the courage to line his cylinders with porcelain or "French burr," and to grind wet, filter-pressing the slip and drying the product to within 5 per cent. of absolute dryness, he would have the pick of the market. Wet ground flint can be lawned, dry ground cannot, and this alone is a strong argument in favor of the wet method.

But, as a society, in the face of the fact that all the millers are grinding dry and all the manufacturers are mixing dry, we cannot, I fear, recommend any such standard as that which obtains in England. Unless we give the committee some definite instructions or prepare the way by preliminary work, it will not do much good.

Mr. F. W. Walker: The remarks of Prof. Binns are very much to the point and I think all of us, possibly, are familiar with these conditions. The grinders of flint and spar will not voluntarily grind finer. I had quite a talk with

one of them a few weeks ago, and he said they could not do it. I had just been talking with Mr. Mayer, and he said that to grind as fine as Mr. Mayer wanted it, would make the material cost double the money. He said, "Would you pay it?" I was not prepared to say whether I would or not. I was simply advocating along the lines of Mr. Mayer's paper. I think the subject wants to be thoroughly considered, but I do not know any one better able to consider it, and make report, than the committee suggested.

SUBSEQUENT COMMUNICATION FROM MR. ERNEST MAYER.

Although not present at the meeting, I am very glad to have the chance of seeing the stenographer's notes of the account of the discussion on my paper.

I fully expected, in fact anticipated, the criticism made by several that the grinders of flint and feldspar would protest against any change in the present method of grinding. My answer to that is this: That as a matter of fact the grinders of flint and feldspar don't know how coarse or fine they are grinding, and my experience is that they grind material as short a time as they possibly can, and the only limit they admit is when the buyer gets a car load of material that won't go through his lawns and won't pay for it. Then, and only then, will they grind finer, unless it so happens (as has many times been done) the potter will charge his lawn to suit the coarser flint.

My paper was written as a protest against the haphazard method of the grinding now in vogue, and, while the point was omitted in my paper, I fully intended to bring out the fact of the great irregularity in grinding in the different cars delivered.

This whole matter is a very simple business proposition and resolves itself into the following: The flint grinder has a grade of flint to sell at a certain price which is ground a certain number of hours, which we will call his *regular flint.* Now for every hour's grinding after that point a fixed sum should be charged, and it will then be up to the manufacturer to decide what he wants.

A committee appointed by this association could ascertain exactly what the finer grinding meant by making pieces of ware from flint and feldspar ground in the different number of hours, and if the results warranted it, after the results of the experiments had been laid before the association, each member would ~~would~~ take advantage of the information gained and govern himself accordingly.

I am not foolish enough to think that my paper will be the cause of revolutionizing the flint and feldspar grinding business, but if the remarks I have made carry any weight, by the arguments used to substantiate them, then my paper has accomplished its mission, viz.: that finer ground material than we now get is one of the means of making more reliable and better ware.

There is one matter to which I would like to call the association's attention, and that is, what is a No. 12*s* lawn? As a matter of fact we come to these meetings and talking about glaze or body being sifted through a No. 12 or No. 14 lawn, it appears to me that no two of us are talking about the same thing. As an example: Professor Binns in discussing my paper says, "In England the materials are prepared and lawned in the slop state, the lawns are 16 and 18 for common ware." Now, evidently, we are not talking about the same thing, because if the common ware goes through an 18*s* lawn, what kind of a lawn do they use for the best ware? Except for stain, I never heard of a lawn being used either here or in England finer than 16.

My understanding of a 12*s* lawn is that it means 30 meshes to the ¼ inch, or 120 meshes to the inch; a 14 lawn 35 meshes to the ¼ inch = 140 meshes to the inch, and a 16*s* lawn = 40 meshes to the ¼ inch = 160 meshes to the inch; but I think the question of the names and number of meshes to the inch ought to be settled and to arrive at an understanding of what the various sizes actually mean in count.

CRYSTALLIZED GLAZES.

BY

WILLIAM H. ZIMMER, PH. D., COBURG, GERMANY.

During the first three years of the existence of this Society we have added quite a good many valuable contributions to the knowledge of silicates. Silicic acid in its various forms has occupied our attention more than anything else, and all papers tend to demonstrate the importance of fineness and most complete distribution. When older methods stopped, after showing that a certain amount of silicate matter was present, we went one step further in trying to decide, if it was qualitatively suitable to the purpose as well as quantitatively. Our transactions contain most important researches in regard to tensile strength of clay-mixtures, plasticity and the relation between plastic clays and the non-plastic ingredients of ceramic bodies. Glazes and fluxes have had their share in our discussions, and even the origin of kaolin, and the nomenclature of the silicates has been touched upon, not to mention all the papers treating on the subject of firing kilns, and similar topics, in which the manufacturer of brick is much interested as the manufacturer of fine china.

Yet, to be frank, there seems to be a large deficiency in the knowledge of our ceramic bodies themselves, and I almost believe that the slow progress in establishing uniform rules and tests in ceramics is partly caused by insufficient knowledge of the very foundation of our ceramic art. What are our bodies and glazes? In some of them, baked at a very low temperature, the various components have hardly entered into a chemical action and maintain as finished ware more or less the nature of a mechanical mixture. Others become quite uniform, and seem to undergo such an intense change, that the final product appears to be almost a chemical compound. However, the chemists claim that a chemical

compound cannot be still considered as a union of various molecules; but where can we draw the line between a chemical compound and a union of various molecules in our ceramic products? May we consider the translucent hard porcelain as a well defined compound, or is it not rather still a union of molecules, of substances partly dissolved, partly suspended, in the melted feldspar? As Prof. Orton said in one of his previous papers,* we have been working for years with test tubes and balance, seeking to explain the marvelous differences and similitudes, but we have decidedly neglected the use of the microscope, and I would like to urge the members of our society to become microscopists and to open up new methods, which will not only allow us quick investigation, but will very likely lead to a more thorough knowledge of ceramic bodies and materials. Such methods might also give us a chance to discover in our clays and kaolins a variety of the rarest elements, which we could not detect with our slow chemical analysis, but which undoubtedly will have certain influences.

There might be a way of crystallographic analysis. We all know, that in chemistry we crystalize a substance repeatedly in order to purify it. The process of crystallization is of the utmost importance, and we shall advance more rapidly in ceramic theory, if we devote more attention to crystals and crystallization. In kaolin, as well as generally in ceramic bodies, the crystals are very fine grained, but of late glazes with splendid crystallizations have occupied the attention of the ceramic world, and although those articles with crystallized glazes are too difficult to be manufactured on a large scale and too high priced to become a staple article, they are very interesting from a theoretical point of view. They are, at least, a start in a new direction and I beg permission to occupy some of your time in describing the methods of producing them.

Our glazes are more or less perfect glasses, in very thin layers and may be considered as solutions of silicates, which although not uncrystallizable, do not flash readily into the crystalline state. However, those glassy silicates form

*Trans. A. C. S., Vol. II, page 100.

definite crystalline compounds, if given a long time to cool. Actually, the crystalline or glassy conditions are more or less accidents of cooling. Crystalline segregations are not new in colored glazes. Aventurine effects are found on Japanese vases made centuries ago, and I have now in my possession a Japanese vase, showing tiger-eye effects on some parts, which was certainly not made within the last twenty years, even if I do not venture to determine its true age.

Dr. Maeckler, by request of Director Dr. Heinecke, of the Royal factory at Berlin, who had purchased some Rookwood vases at the World's Fair, 1893, for the museum of the factory, made the first scientific investigation of the phenomenon, which was published in 1896. Aventurine glazes have been made by various factories in the United States and in Europe. I recently received a nice collection from Egersund, Norway, but I do not know of any one who has reached the perfection of the crystalline glazes of the Rookwood pottery. However, the technique of crystallized glazes was not further developed, until at exhibitions at Paris and Brussels and also at Stockholm in 1897, the French National factory of Sevres, the Royal factory at Copenhagen, and Rohrstrands Aktiebolag, of Stockholm, came out, almost at the same time, with artistic vases covered with crystallized glazes, while the firm of A. Bigaud & Co., in Paris, was successful in the same direction on stoneware. In 1898 the Royal manufactory, of Berlin, followed with some splendid specimens, and of late quite a few factories have been successful in producing crystallized glazes, and although these art goods cannot be produced by the thousands, the time has passed when the formation of crystalline glazes could be looked upon as a mere accident.

It seems as if the very first study on that subject was made by Ebelmen as early as 1847 – 1852, but the credit as inventors of those crystallized glazes is due to Charles Lauth and G. Dutailly, who furnished a cup and paper on the subject for the museum of the National factory at Sevres on September 19th, 1885. An interesting article, "Sur les Couverts de Porcelaine," by Chas. Lauth and

G. Dutailly, is to be found in the book: "La manufacture nationale de Sevres, 1879–1887," par Charles Lauth, in which they say:

By introducing oxide of zinc into glazes, which increases only slightly the fusibility of the glaze, it is possible to obtain highly basic glazes, which form during the process of cooling small crystals of silicates or more likely of oxide. The best crystals were obtained in a glaze of the following mixture, melting at 1350 deg. Cels.

Pegmatite	55.60%
Sand	16.00
Kaolin	4.40
Lime	12.00
Zinc Oxide	18.00
	106.00

This would correspond to the following composition of the glaze:

SiO_2	57.49%
Al_2O_3	11.68
CaO	6.72
Na KO	6.12
ZnO	18.00
	100.01

In another short paper, read before the International Congress for Applied Chemistry at Vienna, 1898, Clement of Copenhagen describes his experiments with the silicate of zinc on the hard porcelain of the Royal factory, Copenhagen. On the porcelain, which was first heavily glazed with the regular glaze and fired as usual, he applied with a brush a second heavy coat of $SiO_2 + ZnO$. After the second glost fire the glaze appeared to be saturated with small crystals, which he claims to be crystals of the natural silicate zinc, Willemite, Zn_2SiO_4. In his glazes, which must be burnt in oxidizing fire, the coloring oxides of metals gives the following effects: Oxide of copper celadon-green, oxide of cobalt, blue, chromium and tin together a yellow-red and the oxide of nickel, which would generally cause a brown color, gives in combination with the silicate of zinc a Persian blue glaze with blue crystals.

A more recent publication of G. Vogt, technical manager of the National factory at Sevres, says that the first crystallized glazes were made at Sevres in 1884. Since then the process has been greatly improved and is applied with good chances of success to stoneware as well as to porcelain. It has been found of great advantage to fritt all materials for the second or crystallizing glaze-coat in a strictly oxidizing fire, for which fritting crucibles are used. He gives the composition of two fritts in practical use at Sevres as follows:

	I	II
Pearl ash (K_2CO_3)	138	69
Zinc Oxide	162	202½
Flint	360	350

Both fritts were mixed; best result was obtained by mixing 35 parts No. I and 15 parts No. II.

A yellow crystallized glaze was obtained by fritting

	III
Pearl ashes	138
Zinc Oxide	162
Flint	300
Rutile	82

15 parts fritt No. II and 85 parts fritt No. III are mixed to good advantage. Rutile contains a good many impurities, principally ferric oxide, and this seems to be the coloring agent, while chemically pure titanic acid will give pretty colorless crystals.

Summing up all these publications, there seemed to be no doubt, but that the silicate of zinc was the essential substance, which, being dissolved in the melted, liquid glaze, would separate again in slow cooling, and I concluded by following this general idea, it would be impossible not to obtain crystals. I proceeded, therefore, to fritt in equivalent proportions pure zinc oxide and silica, using a 99 per cent. dry ground flint. Then I prepared a thick slip by mixing the finely ground frit with water and applied a heavy coat on various small articles of our Wheeling pottery fancy goods. They had been through the glost-kiln before, and for this second glost-fire, in order to obtain crystals, I placed them in a covered pot, put the latter into a large sagger, which I filled solidly with sand, placed the whole in the

middle of the second ring, well protected from any possible draft after the large kiln would be open, and felt satisfied that I had done everything in my power to procure a very slow cooling off. But the result was anything but gratifying. The very best that I could show for all the trouble were some white formations like moss, which proved to be something like small crystals under the magnifying glass, but which were quite different from the splendid specimens I had read about.

I had no chance to investigate any further, but of late my observations were confirmed by the experiments of an Austrian ceramist, who published his results under the anonyme "Bries" in No. 2 of the Sprechsaal, 1902.

He started from a china glaze of the formula

$$\left.\begin{matrix}0.4\ K_2O\\0.6\ CaO\end{matrix}\right\}\ 0.5\ Al_2O_3\ \ 4.5\ SiO_2$$

and increased the basic side by adding one equivalent ZnO.

The new glaze which had to be fritted, would correspond to the formula

$$\left.\begin{matrix}0.2\ K_2O\\0.3\ CaO\\0.5\ ZnO\end{matrix}\right\}0.25\ Al_2O_3\ \ 2.25\ SiO_2$$

The body he was experimenting with had the following composition:

Clay substance	35%
Flint	40
Spar	25

The trials were fired at a temperature of Seger cone 8 that is at a heat quite frequently reached in our American biscuit-kilns. But neither the glaze mentioned above, nor a plain potash zinc bisilicate

$$\left.\begin{matrix}0.3\ K_2O\\0.7\ ZnO\end{matrix}\right\}\ 2\ SiO_2$$

gave the desired result. Then he continued: "I did not succeed in obtaining gratifying results as long as I restricted my experiments to glazes without titanic acid. There was only a tendency to small formations, which sometimes could be proved to be crystals under the microscope. In consequence I went one step further and fritted another glaze, in

which part of the silicic acid was replaced by an equivalent amount of titanic acid,

$$\left.\begin{matrix} 0.3\ K_2O \\ 0.7\ ZnO \end{matrix}\right\} \quad \left\{\begin{matrix} 1.7\ SiO_2 \\ 0.3\ TiO_2 \end{matrix}\right.$$

obtained by the following mixtures:

Pearl Ash	18.43%
Zinc Oxide	25.24
Flint	45.39
Rutile	10.94

"The glaze became opaque. Titanic acid does not go into a complete solution in the liquid glaze, its molecules remain more or less suspended and this circumstance seems to be very material for the formation of large crystals. Besides a hard biscuit, a long period of an evenly high temperature at the end of the burning and, as mentioned before, a slow cooling are the most favorable conditions." He also recommends to burn the crystallizing glazes in double saggers and calls attention to the necessity to have the inside of the sagger well glazed, as a porous sagger would absorb alkalies from the glaze; which might be detrimental to the crystals. Another interesting item is the fact, that in colored crystallizing glazes the crystals sometimes have taken up the coloring oxides and appear in their color, while the ground shows a different shading.

The effects obtained by this application of titanic acid are really wonderful and I exceedingly regret, that I cannot send along some of the fine specimens standing before me while writing.

DISCUSSION.

Mr. Hasburg: I have a small specimen of the Copenhagen crystalline glaze with me which I will pass around if the members care to see what this paper refers to.

Mr. W. D. Gates: One thing which has struck me is the use of the microscope in the study of crystalline glazes. I was much interested in having it pointed out to me that we we manufacturing a matt glaze which was a mass of crystals. Until Mr. Burt called my attention to it, I did not know what we were making.

Mr. Ray T. Stull: I was interested in Dr. Zimmer's paper, as I happened recently to find in Sprechsaal the same article which he speaks of, about crystalline glazes. I immediately became very much interested. I weighed up a small batch of glaze and fritted it, and applied it to a hard porcelain body which burned very dense at cone 8. The factors which go to produce a crystalline effect were given in this article as, first, a continuously oxidizing fire; second, a gradually increasing temperature; third, a gradually decreasing temperature; and fourth, the elimination of the alumina. The composition of this glaze was

$$\left.\begin{matrix} 0.3\ K_2O \\ 0.7\ ZnO \end{matrix}\right\} \begin{matrix} 1.7\ SiO_2 \\ 0.3\ TiO_2 \end{matrix}$$

This glaze is free from alumina, and when fused, lies quietly. I think the paper said the titantic acid did not go into solution. In the fritt I made, I found it did. After making the fritt, I applied the same in a dab in the center of a small tile. I did not have access to a kiln having the proper temperature at that time, and so I put it back into the fritt kiln, where it is almost impossible to maintain oxidizing conditions, or to raise the temperature slowly, or to cool slowly. However, I did the best I could with these unfavorable conditions. On examining the results, I found the center was perfectly clear, but around the rim of the glaze were these little flossy, silky crystals, which we saw in the piece which Mr. Hasburg passed around.

Professor Binns: In regard to the production of crystalline glazes, it seems to me that it must always rank with the Rookwood Tiger Eye or Gold Stone, as more or less of a ceramic curiosity. It must not be supposed that it will be of commercial value. It ranks with the fine art productions which made the old Chinese so famous. Such productions are fine art and not science. I am coming more and more to the conclusion that the production of fine ceramics is as much a matter of art as of science. This is illustrated by a conversation which I had with a Japanese student in my school regarding the production of copper reds. He says that the most successful man in Japan in the production of copper reds told him that about one piece out of two hundred is

successful, and moreover he finds it a mistake to use artificial material if he can get the natural. He won't use ground silica in any form. He gathers together a mass of rice husks and calcines them to procure finely divided silica from the ash. This opens the limitless field of research (if it was limited before, which I doubt). The Japanese potter who picks up a stone by the roadside and uses it obtains a result which he cannot duplicate, but he may get a fine thing. The production of crystalline effects belongs to the same class of beautiful and rare ceramics, of which we are beginning to take cognizance. We are coming to see that there is more than cold science to be reckoned with. It is the art which make a physician a good physician, and the art which makes a potter a good potter. It is the art which has made some practical men superior to some men depending only on science, and which we always have to take into account in the production of finer work.

Mr. W. D. Gates: Regarding that Japanese silica derived from rice husks: doesn't that produce an intensely fine silica?

Professor Binns: That was the point in glazes. This intimate mixture of silica and carbon, which they depend on to help the reduction of copper to the red color, was secured from rice husks.

Mr. J. W. Hasburg: Concerning copper reds being so accidental as one in two hundred,—that might be the case with the man who did not know his business and does not know how to get the copper red. I do believe it is a fact from a scientific standpoint, that it is a purely chemical process. It is produced by special conditions and chemicals, and when the conditions and chemicals are right, the red will be produced. I believe that where the production of copper red is thoroughly understood, it is not a case of one chance in two hundred, but that it will be produced nearly every time with little variation. I have succeeded in producing these reds and, therefore, can speak from experience.

Professor Binns: Just as I said before—the production of copper red is not under the control, absolutely, of any known set of conditions. Of course there are special conditions to produce it, but at the present time we do not know

exactly what they are. We could hardly find a higher exponent of science than Seger; yet his copper red is not to be compared with that produced by the famous Lang Yao family in China.

Mr. W. D. Gates: My experience with copper red is that you want to get your theories in good shape, go to work and flirt with it — then do something else.

Professor Binns: It is a matter of common knowledge that one of the Havilands of Limoges spent 150,000 francs in an effort to produce copper reds, and after some years consumed in experimenting, gave it up as a failure. Looking at some of his samples in the light of present knowledge, I think I can see where he failed, but I don't believe I could do any better.

STONEWARE SLIPS OR ENGOBES.

BY

SAMUEL GEIJSBEEK, DENVER, COL.

Engobes or slips are natural clays or clay mixtures designed to cover other clay bodies, whose color we desire to conceal. They also can serve as ground-layers for decorative effects, in case the article is to be decorated. Generally an engobe is used to increase the value of the product on which it is applied. In these cases, the engobe is a more expensive mixture than the clay body on which it is used. Sometimes its value is the same as the clay on which it is applied, and only serves to cover the color.

The use of engobes is a very old one, and history tells us that the Greeks already used engobes in three colors — white, red and yellow. Edwin A. Barber, in his book, "Pottery and Porcelain of the United States," says in regard to engobes: "Perhaps there are no products of the potter's art more interesting to the antiquary and the collector than the rude 'slip-decorated' pieces which were made in England and Germany during the seventeenth and eighteenth centuries."

Engobed ware was made in Pennsylvania as early as 1762 and the industry flourished until about 1850. Engobed ware was not made thereafter in large quantities until the art potters took it up some years ago. Stoneware manufacturers are now using it more and more, and we find quite a nice variety of "white lined" clay products throughout the country.

In the art branch of ceramics, engobes are extensively used. These engobes are compounded in order to obtain decorative effects and are commonly termed "colored slips." Terra-cotta manufacturers are using engobes to a very large degree, and produce some very good effects with the same.

The nature of engobes can be twofold. They can be white or colored. In the first instance, they are mixtures of

pure white burning clay materials, and in the second way, they can be natural colored clays or mixtures of clay, tinted with color-producing mineral ingredients.

On stoneware, the engobe is usually white, while on artware and terra-cotta, mostly colored.

Engobes are mostly applied to the ware in the green state, either by dipping or spraying. Experiments have been made to apply the engobe on the dry ware, with various success. It is evident that both ways can be used, and it depends upon the product on which the engobe is to be applied.

Engobes can be covered with a glaze, or they may themselves form a vitrified coating. When an engobe is covered with a glaze, it can be applied to the engobe in green state, or after the engobe is burnt once. To the first class belong stoneware, and to the other class, artware.

In Germany we find a few clays which are put on the market and are specially adapted for engobe purposes. We do not have any special grade of this kind of clay on the market in this country, as clay-miners never have made any effort to foster that trade.

In order to make a clay valuable for white engobe purposes, it should possess a certain degree of plasticity; it should burn white; it should be able to adhere to another clay in such a way as to give a uniform coat when applied as a thin slip; it should have the same shrinkage as the clay on which it is applied, and should be able to hold a glaze without defects.

According to Dr. Seger, the two German engobe clays which are on the market have the following composition:

	Kaschkau Clay	Cologne—Meissen Clay
SiO_2	63.17	62.52
Al_2O_3	25.09	25.57
Fe_2O_3	0.64	0.92
CaO	0.35	0.65
MgO	0.26	0.10
K_2O	0.80	1.04
H_2O	9.70	9.27
	100.01	100.07

Rational analysis of both:

Clay substance.	67.82	72.05
Feldspar.....	1.25	0.10
Flint.....	30.93	27.76

I have so far been unable to find in America a white burning plastic clay which would answer for engobe purposes, and which would have nearly the same composition as the German Clays.

The clay mined and marketed by Fischer, Black & Co., of Newport, Pa., is the only clay of which I know which comes close to the German engobe clays cited above. The analysis is given below:

	Analysed by Langenbeck	Analysed by Geijsbeek
SiO_2.	62.89	62.30
Al_2O_3	26.14	27.07
Fe_2O_3	0.57	0.63
CaO	0.60	0.64
MgO.....	0.75	0.13
K_2O	2.32	1.85
H_2O.....	7.55	7.74
	100.82	100.36

Rational analysis:

Clay substance.	70.81	68.70
Feldspar.....	2.17	2.42
Flint.....	27.84	29.24

I have made some thirty different experiments with this clay for engobe purposes without any satisfactory results, and have come to the conclusions that this clay does not answer for that purpose, although it is in chemical composition nearly like the German clays.

In making further experiments along this line, I used various American kaolins as they are put on the market, and of the numerous varieties tested, the Florida kaolin and the Graham kaolin answered the purpose best. I first used the Spencer kaolin, with various success, but abandoned the same later on for commercial reasons.

In conducting such experiments, there are at present no rules which could be used in guiding one in order to obtain satisfactory results, and I am sorry to state that so far, my experiments have not yet given me a basis from which to formulate a rule which would be useful in making further experiments.

It is, strictly speaking, an experiment in which plasticity and shrinkage play the greatest part.

I have found that in making colored engobes it is much easier to obtain a satisfactory clay than in making white engobes. For such purposes I have been able to use regularly the ball clays without any additions. As coloring material, I have found that the ordinary underglaze colors on the market answer the purpose very well.

In making engobes for stoneware, it was always desired to have a white engobe, which could be used for inside work, such as for jars, milkpans, buttercrocks, churns, and so on. Stoneware people call these engobes under the familiar name of "white linings or enamels."

My first experiments were conducted on washed stoneware clay as used by Sherwood Bros., New Brighton, Pa.

The rational analysis of this clay is:

Clay substance	66.54
Feldspar	2.46
Flint	31 02

I determined first the relative shrinkage between the Florida kaolin and the stoneware clay, as I intended to use the Florida kaolin as a basis for the experiment.

A thin coat of kaolin slip on the stoneware would be shivered off entirely, after burning, showing that the kaolin shrunk more than the stoneware clay.

The addition of non-plastic material was next tried. 75 per cent. of kaolin, and alternately 25 per cent. of flint, feldspar and whiting. Of these three experiments, the two last showed the best results, and further experiments were made in that direction.

Engobe Number	B_2	B_3	B_4	B_9	B_8	B_7	B_5	B_{19}	B_{21}	B_{20}	B_{22}	B_{24}
Florida kaolin	75	75	75	75	75	75	75	70	70	65	65	65
Brandywine Feldspar	25	..	20	15	12.5	10	5	10	15	10	25	30
Whiting	..	25	5	10	12.5	15	20	20	15	25	10	5

Of the above twelve experiments it was found that B_7 answered best for stoneware slip, and next best was B_{24}. The difference between the two was that B_7 was whiter than B_{24}. None of these mixtures peeled on the stoneware clay, the only defects they showed was cracking in drying on a few pieces. The only trouble with B_7 was that the shrinkage was just a little less than the body, so that when applied on the outside of the ware it would crack off the edges of the body. Therefore it was advisable to see what another kaolin would do. Spencer kaolin was substituted for the Florida kaolin. This substitution obviated the trouble above mentioned at once, and the mixture gave very satisfactory results,

While engobe B_7 did not shrink enough, and none of the other experiments showed any improvement in that respect for outside work, I concluded that the cause was due to too much plastic clay. I calcined some of the Florida kaolin, and made mixtures with the same formulæ B_7, but varying proportion of calcined kaolin. I took account of the loss of weight in the calcined kaolin, in weighing it into the new test batches, and obtained an excellent engobe for outside work. B_{29} gave the best results.

Engobe Number	B_{27}	B_{28}	B_{29}
Florida Kaolin, Raw	60	50	35
Florida Kaolin, Calcined	15	21.5	34.5
Brandywine Feldspar	10	10	10
Commercial Whiting	15	15	15

These few experiments show that there are several ways to get a suitable "white lining" or engobe for stoneware, and judging from past experience with the above engobes, I think that B_{29}, where calcined clay was used, would give in the long run the best results, especially on stoneware, where

body, engobe and glaze are all brought to perfection in one burn.

All samples were fired at cone 8, and the glaze employed for all engobes was

$$\left.\begin{matrix}0.3\ K_2O \\ 0.7\ CaO\end{matrix}\right\}\ 0.5\ Al_2O_3\ \ 4SiO_2$$

In connection with these experiments, I beg to call your attention to the solubility of bodies and engobes in glazes. When I started these experiments, I was told to use the regular white stoneware glaze employed by Sherwood Bros. at that time. I judge it was a zinc-boro-lime glaze, but do not know its composition. On using this glaze, all engobes showed that the layer of white material was attacked to such an extent, that the body was plainly visible, and the effect of the engobe was lost.

Engobe glazes should be so compounded that their solvent power is very low. Easily fusible glazes, which do not need a high fire to be called "finished," will not dissolve any important part of the body, if they are not fired higher than their proper finishing point. But when fired at a high heat, their solvent action on saturating themselves with the ingredients of the body, is very great, and such glazes can not be used for engobe purposes. Glazes, as generally used in stoneware potteries, high in alumina and silicic acid are usually well adapted for engobe purposes.

Some time ago I was called upon to make engobes suitable for western stoneware clays. I soon found that engobes which work well on one clay, may not work so well on another.

The clays in questions were the Colchester, Ill., and Tennessee, Ills., stoneware clays as used in Macomb and Monmouth, Ills.

The rational analysis of these clays is as follows:

	Colchester	Tennessee
Clay substance ...	54.60	65.70
Feldspar.....	4.51	2.25
Flint.....	40.89	32.05

The Tennessee clay resembles very closely the New Brighton clay in rational analysis, and works about as well.

Engobes B_7 and B_{24} did not work well on these clays. B_7 would crack and lift up in drying, and peel afterwards, while B_{14} would only crack.

A substitution of Florida kaolin for Graham kaolin was made. It was found that Graham kaolin No. 1 was a better product than Spencer kaolin. It shows the same properties as Spencer kaolin, and has nearly exactly the same shrinkage. In rational analysis they are nearly alike.

	Graham Kaolin No. 1	Spencer Kaolin
Clay substance	95.88	94.12
Feldspar	0.12	1.50
Flint	4.00	4.68

The results of the substitution, B_{51}, was an improvement over B_7. The only defect was that when the glaze was applied, the engobe would blister. After some experiments it was found that a combination of engobe B_{51} and B_{24} would give good results.

Engobe B_{56} which was adopted as satisfactory for both the Colchester and Tennessee clays had the following composition:

Florida kaolin	32.5
Graham kaolin	37.5
Brandywine feldspar	20
Commercial whiting	10

This engobe worked well on dry and green body; it could be dipped in and outside at the same time; and the burning was all done in one fire.

As it seemed strange that flint could not be used so far in engobe, I have started experiments on that subject, but as yet I have been unable to finish the same or come to any conclusion.

As stoneware glazes have a tendency to pin-hole, it often happens that the engobe underneath will be discolored in use, by absorption of dirty liquids through the glaze, and with a view to obviate this trouble, I have started another set of experiments which will give vitrified engobes on stoneware bodies. The results so far have been very satisfactory, and I have produced two engobes which get around this trouble.

One experiment was started on the line of vitrifed bodies, and results were obtained with a formula of the following composition:

$$1\ K_2O \quad 2.15\ Al_2O_3 \quad 10.80\ SiO_2$$

and the other experiment was started on the stoneware glaze line. It had the formula

$$\left.\begin{matrix}0.50\ CaO \\ 0.50\ K_2O\end{matrix}\right\}\ 1.00\ Al_2O_3 \quad 4\ SiO_2$$

All experiments were glazed with the stoneware glaze as mentioned before and burnt between cone 6 and cone 8 heat.

DISCUSSION.

Mr. W. J. J. Bowman: I do not know that I have anything to add to that paper. My experiments in a certain way have followed much the same lines as those outlined in the paper, and his experience has been mine. I would like to say that I think it is necessary to have a proper body underneath, as well as a proper slip. In other words, I think there are certain bodies to which we cannot make a slip stick. At least, that has been my experience.

I would like to raise one point, and that is whether the author means that the slip comes off in firing or whether it comes off when applying it, or drying? He mentions in one place that the slip peels off the outside. In some cases, I find it will do this, if the shrinkage of the slip is not sufficient in the green state; in other cases, it will stay on in the green state but come off when fired, which is due to quite another condition. One fact which I have experienced and never could understand is this: I have had a case where the shrinkage of two different bodies would be entirely different and yet the same slip would apparently work alike on either. The shrinkage of the body did not seem to take much effect on the slip. It would shrink down with one body, which shrank twice as much as the other.

Professor Orton: Do you mean the shrinkage occurring in firing or in drying?

Mr. Bowman: In firing. One would shrink an inch to the foot and the other an inch and a half, and yet the same slip would apparently work as well on one as the other.

Mr. Stanley G. Burt: The slip, however, would have a still greater contraction than the body in both cases.

Mr. Bowman: Yes.

Mr. E. C. Stover: Is not the explanation to that, that the deficiency, as it were, of certain ingredients in the mixture is supplied by an excess of it in the body? I think the line of experiments made by Mr. Binns seemed to show that. Under a very hard fire, the mixture of engobe being deficient in one of the ingredients, and there being an excess of that in the body, the hard fire will make it borrow, as it were, from the body and therefore change its shrinkage and make it fit the body.

Mr. Burt: I think the slip undoubtedly undergoes a chemical change, much as the glaze does. When you get a slip which has an excess of contraction, the moment you have vitrification of the slip, there is an incipient action on the body; so if the the slip vitrifies, it has entered into a certain chemical combination with the body. As long as you have a porous engobe, there is a mere mechanical bond which is easily broken; but as you approach vitrification of your slip, you get a chemical bond which is more difficult to break.

Mr. Bowman: The question I raised was how the slip adjusted itself to the different shrinkages and did not tear.

Mr. Burt: It has a certain elasticity, you know. If you should go beyond that limit of elasticity of the slip, it would tear.

Professor Binns: I think the probable explanation is that the slip in the first place was adjusted to the larger body. If it had been adjusted to the smaller shrinkage, it would scarcely have accommodated itself to the larger. The extra shrinkage could be taken up by the body, but if it had been adapted to a smaller one in the first place, it would peel on the larger. I will ask Mr. Bowman if he did not find, after all, that the cohesion of the slip and the body was less important than the cohesion of the glaze and the body—providing the upper and lower agreed, the intermediate layer did not so much matter? If the glaze agrees with the body, the slip can have a wider range. And if you have a glaze

which will shiver on the main body, even if you apply a good slip to it, it will shiver, the slip peeling right off with it.

Mr. Ray T. Stull: I happened accidentally to produce something in a recent experiment which may throw light on the subject. I made a China body and casted two small vases from it, using the same mould. One I packed in flint, inside and out, and burned to cone eight. The other I did not pack in flint, and burned to cone four. To my great surprise, the one burned to cone eight was larger than the one burned to cone four. The flint on the inside of the one finished at cone eight prevented shrinkage, while the one not packed in flint was perfectly free to shrink.

Professor Orton: I am glad Mr. Stull rose to make that point, as I was about to ask him to do so. It seems to me a very pretty little point with a clear application in this connection. He showed me these trials, and I was surprised to find such difference of size in two vases, cast in the same mould, of the same slip. Both were vitrified, both thoroughly hard, both translucent. The quality of the translucency in the one which shrunk the least, was somewhat deficient as compared with the other; but this may have been due to the fact that the flint packed inside of it had adhered slightly to the inner surface, and did not come off perfectly clean, and thus made a slight lack of translucency. You can see the shadow of your finger through the walls of the vase in both cases. The one which had a mechanical bar to shrinkage, underwent vitrification without condensation, and the one which had no bar to shrinkage, underwent vitrification and condensation as well. If this would occur in the case of Mr. Stull's porcelain body, I do not see why it would not work in the case of a stoneware slip.

Mr. D. C. Thomas: Which of the two vases shrunk the most ?

Mr. Stull: The one finished at cone four, which had no resistance to shrinkage. I might add to that, that the difference in shrinkage between the two was at least three per cent. The one burned to cone four shrunk at least three per cent. more than the one burned to cone eight—I presume more.

Mr. Burt: I would like to ask Professor Orton how that bears on the question of Mr. Bowman's.

Professor Orton: We have here a case where a porcelain vase, not dissimilar in composition to the stoneware slip, had a mechanical bar to shrinkage in the shape of a whole lot of flint packed inside of it. That vase was carried up to the vitrification temperature, where ordinarily it would shrink greatly. The little vase which was not packed with flint had an opportunity to shrink and did not shrink. The other one which could not shrink, went on and vitrified all right, and became translucent, showing that the chemical reactions took place in their usual order, but that the vitrified walls of the vase were sufficiently viscous to take the size of the mass of flint which they held inside.

Now, Mr. Bowman says that he put a slip, which we will assume is similar to a porcelain body — (I don't know how closely similar, but of the same general class of substance)— he put this slip on two bodies. One body shrinks a good deal and the other less. It stays on both without rupture, and he asks why. It seems to me that the cases are parallel. There is a mechanical bar to shrinkage in both cases. In one case it was the flint with which the little vase was filled, and in the other case it is the comparatively non-shrinking body upon which the slip is fastened.

Mr. Burt: That would necessarily assume that the high shrinkage did not take place until after vitrification had taken place; because, as I said before, there is nothing but a mechanical bond between the clay and the slip and before vitrification any tension of any extent would very easily rupture that bond. So if we are to assume that vitrification of the slip enabling it to hold to this body is due to the fact of a bond in any way equivalent to that between the vase and the solid body of flint, we must necessarily assume a very firm bond to the clay underneath, and I do not think we can consider that possible until vitrification has set in. I understand that the bulk of shrinkage takes place at the vitrification point, not before. So you have got to get your bond on the clay before vitrification; otherwise you will have a tear.

Professor Orton: I do not see it that way. It seems to me the shrinkage undoubtedly takes place *during* the process of vitrification, and there is no need of a bond previous to that point, except as the drying shrinkage may require it, and from the minute you begin firing until vitrification sets in, there is little change in volume. If the slip and stoneware were separate, they would probably shrink differently, but being fastened on each other, the bond develops by vitrification between the two fast enough to neutralize the strain produced by this disparity in shrinkage rate which would occur if they were free. That is the way I explain it — it is a sort of progressive attack on the body, as well as porgressive change in the slip itself.

Mr. Burt: I feel that Prof. Orton's explanation is undoubtedly correct. If we make a cone from a glaze mix and completely fuse it, we have as a result a small drop of glaze. Take the same amount of glaze, spread it on a piece of ware, fire it, and we have this glaze extended over a large space. This seems to me much the same phenomena that we have in the vitrified slip. We may apply our glaze to a burnt piece or to one of raw clay. It will hold equally well. The same is true of an engobe. It may be applied on the clay or on the biscuit, and will hold equally well in either case, provided it is properly compounded. It is absolutely necessary, however, that there be a proper mechanical bond between body and slip, or body and glaze, when vitrification sets in. If this does not exist, a glaze will crawl and an engobe peel.

Seger says, that in adjusting an engobe to a body, the rational analysis of each should be carefully considered. I had hoped Mr. Geijsbeek would give us his experience on this subject.

Professor Binns: I think there is an interesting connection between that experiment and the general practice in porcelain factories where flint is commonly used to hold the shape and prevent shrinkage of the ware. And it would be an interesting study, in this example, to make a microscopic examination of the structure of the two vases. It seems to me possible that the larger body is less dense than the

smaller. But it shows the flexibility in vitreous bodies which can be influenced by mechanical means. I think if the fire had been carried a little further the larger vase would have burst. I also think it probable that cone eight heat was not thoroughly reached in the center of the bed flint. You know that heat penetrates slowly into the center of such a mass. You could not know whether that temperature was in the center of the flint unless a pyrometer could be inserted.

Mr. Stull: I think the comparison I made was a fair one. Both vases were fired in a small sagger and in the same kiln and under similar conditions. Even if the cones did not correctly represent the temperatures, the latter were at least comparable.

Mr. Everett F. Townsend: I would say that there is about the difference of one cone between putting tile in a sagger with sand, and putting it in without sand. The shrinkage in the two cases differs by about the same amount as that occasioned by one cone's change in temperature.

STONEWARE GLAZES.

BY

ROSS C. PURDY, COLUMBUS, OHIO.

The term stoneware, as popularly used in this country, means a grade of pottery made from a natural clay or mixture of clays, which is burnt to vitrification, and in which the body and glaze are matured in one and the same fire. The articles usually made are crude jugs, crocks, receptacles for fruits and dairy products; latterly the line has been increased to include many kitchen, table and toilet articles; in addition, a small quantity of stoneware is employed by the chemical industries, for receptacles, stills, worms, stopcocks, conduits, strainers, and similar wares. This constitutes no item in the general trade, but brings prices far above those of general stoneware. In this country, however, the stoneware has not yet attained the reputation for excellence that is enjoyed by the Flemish, German or Japanese products.

The nature of the body used in the manufacture of foreign stoneware is unknown to the writer, but two receipts given as German stoneware bodies, were found to read as follows:

I.			II.		
	English Blue Clay	25%		Plastic Fireproof Clay	36%
	Kaolin	32		Kaolin	30
	Flint	35		Flint	30
	Spar	8		Spar	4

The American stoneware, with perhaps one or two exceptions, is made from either a single low-grade or No. 2 fire clay, or a mixture of two or more such clays. In nearly all cases the body may be said to be a native, yellow burning fire clay, containing enough fluxes to vitrify it to a blue-gray dense body at about cone 8. It is exceptional, if at all, that a prepared body like those cited is used.

I have also seen German stoneware glazes that figure out to be high-fire fritted glazes. An illustration of these glazes is as follows:

Fritt —	Red Lead	9.1%
	Quartz	32.7
	Borax	27.3
	Whiting	18.2
	Kaolin	12.7
		100.0
Glaze —	Fritt	80%
	Spar	12
	White Lead	8
		100

On calculation, the formulæ of fritt and glaze are found to be respectively:

$$\text{Fritt} — \left.\begin{matrix} 0.136\ PbO \\ 0.244\ Na_2O \\ 0.620\ CaO \end{matrix}\right\} 0.168\ Al_2O_3 \left\{\begin{matrix} 2.20\ SiO_2 \\ 0.49\ B_2O_3 \end{matrix}\right.$$

$$\text{Glaze} — \left.\begin{matrix} 0.20\ PbO \\ 0.21\ Na_2O \\ 0.53\ CaO \\ 0.06\ K_2O \end{matrix}\right\} 0.20\ Al_2O_3 \left\{\begin{matrix} 2.23\ SiO_2 \\ 0.42\ B_2O_3 \end{matrix}\right.$$

The nature of the body and glaze, as given, suggests a ware of much higher grade than any American stoneware. I know of only one instance where an American stoneware potter uses a lead glaze, and I do not know of any that use a fritted glaze.

It must be that in Europe, "Stoneware" includes higher grades of ware than is generally accepted as such in this country.

The nature of the body, as well as the single burn with its slow heating and cooling, precludes the use of lead and boracic glazes from a chemical standpoint. The low price obtained for the ware and the consequent economy of manufacturing, necessitates a glaze that will mature with the body, giving a smooth, glossy coating without having flowed, and which will not be contaminated by direct contact with the fire gases.

Such glazes as are used by American stoneware potters may be classified as follows:

I. Salt Glazes
II. Slip Glazes
III. Bristol Glazes { Clear / White / Colored

SALT GLAZES.

Salt glazing, while fast disappearing from use in the stoneware industry today, is worthy of consideration because of its very interesting chemical reactions and its past importance.

To be salt glazed, the ware is set more open than the ware which is coated with a slip or bristol glaze, so as to expose all the surfaces to be glazed to the free action of the fire gases. The inside of the pieces are glazed with a slip glaze, and are not exposed to the action of the salt vapors.

The heat attained is that sufficient to almost vitrify the body. This is essential in successful salt glazing, for the alkali fumes would penetrate a soft porous body and not give the desired fluxed or glazed surface on the ware.

When the trial pieces drawn show that the body has attained the required density, and the fires have burned clear, salt is thrown onto the fires, either a trifle damp or with wood. Fumes of Na Cl and water vapor are thus generated, the water vapor decomposing the fumes of sodium chloride, setting the alkali free in the kiln to attack the exposed surface of the ware and fusing it into a thin coat of glaze.

The glaze thus formed must naturally approach the formula of slip and Bristol glazes, deriving the necessary Al_2O_3 and SiO_2 from the body. For successful salt glazing the clay must have approximately the same proportion of Al_2O_3 to SiO_2 as is found to exist in the slip and Bristol glazes, viz: from 1:5.5 to 1:7.

SLIP GLAZES.

Slip glazing is the application to the surface of the ware of such clay or clays as will fuse and form a glaze at the heat sufficient to vitrify the body. Such fusible clays are of the ferruginous type, burning to either a red, brown or black.

The Albany slip is widely known for its uniformity in point of fusion and in color. It is a clay mined near Albany, N. Y. Its chemical formula when burned, as given by Langenbeck, is

$$\left.\begin{matrix}0.1954\ K_2O \\ 0.4592\ CaO \\ 0.3454\ MgO\end{matrix}\right\} \left\{\begin{matrix}0.6080\ Al_2O_3 \\ 0.0810\ Fe_2O_3\end{matrix}\right\} 3.965\ SiO_2$$

Slip clays possess some subtle quality given by nature that render them impossible of duplication by mechanical mixtures of the same formulæ. Starting with a ferruginous clay as a basis, adding such ingredients as to duplicate the formula of the natural slips exactly, one would not obtain a glass like or equal to that of the slip glaze.

Albany slip produces a glaze that stands well upon almost every clay body, prepared or natural, without crazing or dunting. It has been observed that lead glazes containing 50 per cent. or more of Albany slip will stand a greater variation in the body than will a lead glaze without the slip clay. What that subtle factor is which renders this clay so valuable and which refuses duplication by mechanical means, is not known.

BRISTOL GLAZES.

A Bristol glaze is one composed essentially of silicate of the alkalies, alkaline-earths and alumina, applicable to green ware, and capable of being burned in open fire with slip glazes. Bristol glazes may be either clear and colorless, white, or colored. The study of clear and colored Bristol glazes will not be taken up at this time.

WHITE BRISTOL GLAZES.

The white Bristol glaze from a scientific standpoint, is a new field for research. Its application is so recent that the ceramic chemist has had hardly time to analyze the scientific causes for its various behaviors, or to ascertain the workable limits of its chemical formula for practical work.

I have not been able to myself carry out any extended research on this subject, but I have at hand the record of a large number of experiments made by a former assistant, with whose methods of work I am familiar, and in addition, I have the trial pieces numbered to correspond to the record. While I would have planned my series differently in some respects, if attacking the problem at the beginning, I still feel that a good deal of value can be gotten from the study of the matter already at hand.

The following notes are therefore to be considered as a digest of these experiments, supplemented by such opinions as my own experience has confirmed in the premises:

I. Oxygen Ratio in White Bristol Glaze.

In the hope of eliciting facts by comparing the oxygen ratio and the ratio of Al_2O_3 to SiO_2 in the glazes of which I have samples at hand, I calculated out the ratios and tabulated them. While it was not found that any definite oxygen ratio, and silica alumina ratio could be said to be the best, it was evident that the best Bristol glazes had an oxygen ratio, ranging between 1:2 and 1:2.5, and silica alumina ratios ranging between 1:5 and 1:7.

From Table I, given later, it is to be noted that even with the oxygen ratio with the limits that seem to be best, the glazes are not good because of physical peculiarities. This illustrates the fact that a Bristol glaze stands between the lead glazes, that are under definite chemical control, and ceramic bodies and pastes that obey chemical laws in but a small part. Chemically, we can increase or decrease the fusibility of a clay body, but the physical properties such as shrinkage, etc., are beyond chemical calculation. It can be said that this or that oxygen ratio is the best in lead glazes, but such is not the case in Bristol glazes.

However, the trials in table I, whose oxygen ration are within the limits of 2—2.5 are better matured and have a better gloss than those of higher or lower oxygen ratio.

II. Al_2O_3 in White Bristol Glazes.

Al_2O_3 in Bristol glaze performs the same function as in lead glazes, being an intermediary element between the fluxes and the acid. In addition to this chemical function, it has a physical function which enters but little into that of a lead glaze, viz: regulation of shrinkage and maintainance of a viscous paste.

It was believed that crawling and pinholing was more prevalent where the Al_2O_3 was high. Desiring to obtain the evidence indirectly, a number of trial pieces showing these defects were chosen and their corresponding formulæ, oxygen ratio, and silica-alumina ratio tabulated.

TABLE I.

No. of the Glaze	Equivalents of the Ingredients.					Oxygen Ratio	Silica-Alumina Ratio
	K_2O	ZnO	CaO	Al_2O_3	SiO_2		
21	0.444	0.444	0.111	0.555	4.44	3.333	8.00
22	0.50	0.388	0.111	0.6	4.44	3.13	7.26
23	0.555	0 333	0.111	0.666	4.44	2.90	6.66
113	0.50	0.40	0.10	0.55	4.00	3.01	7.27
114	0.55	0.40	0.05	0.6	4.50	3.21	7.50
177	0.50	0.40	0.10	0.6	3.21	3.28	5.33
178	0.50	0.40	0.10	0.65	3.30	2.23	5.07
179	0.50	0.40	0.10	0.70	3.40	2.20	4.85
180	0.50	0.40	0.10	0.75	3 50	2.14	4.66
199	0.50	0.40	0.10	0.55	4.00	3.01	7.27
231	0.50	0.40	0 10	0.55	3.25	2.45	5.90
347	0 50	0.40	0.10	0.70	3.60	1.16	5.14
424	0.40	0.45	0.15	0.55	2.93	2.22	5.36
443	0.50	0.40	0.10	0.60	3.61	2 57	6 00
444	0.50	0.40	0.10	0.60	3.80	2.70	6.33
445	0.50	0.40	0.10	0.60	4.00	2.85	6.66
446	0.50	0.40	0.10	0.65	3.60	2.44	5.33
447	0.50	0.40	0.10	0.65	3.80	2.57	5.84
448	0.50	0.40	0.10	0.65	4.00	2.71	6.15

As it is impossible in commercial work to glaze all the ware when at "leather hard" condition, it has become the general practice now to dip the ware when "bone dry," although the finished ware is better if dipped when "leather hard." These trials were dipped when "bone dry."

These trials bore evidence to correctness of the assumption that crawling, in most cases, is due to too much clay. Too much clay means too much shrinkage in clay state, either on drying floor, or in kiln, or both. Too much shrinkage causes cracks in the glaze, perhaps not perceptible at casual glance of the operator, but which develop during the early stages of the burning, leaving on the burned ware a bare spot or seam. As the body exposed by these bare spots and seams does not show evidence of having been affected by any fluxing action, it is safe to presume that the glaze had crawled before it had been fused even to the slightest extent.

.55 equivalent Al_2O_3 seems to be the maximum that is safe to use under the existing conditions.

To see if the converse was true, a few trials, free from crawling and pinholding were selected, and their corresponding formulæ found to be as follows:

TABLE II.

No. of Glaze	Equivalents of the Ingredients.					Oxygen Ratio	Silica-Alumina Ratio
	K_2O	ZnO	CaO	Al_2O_3	SiO_2		
54	0.233	0.4	0.366	0.33	1.94	1.3	6.00
106	0.45	0.3	0 25	0.50	3.50	2 8	7.00
107	0.50	0.3	0.20	0.55	4.00	3.01	7.27
110	0.50	0.35	0.15	0.55	4.00	3.01	7.27
111	0.40	0.40	0.20	0.45	3 00	2.55	6.66
116	0.40	0.40	0.20	0.50	4.00	3.20	8 00
570	0.45	0.40	0.15	0.50	3.00	2.40	6.00
575	0.45	0.40	0.15	0.525	3 15	2.44	6.00

There were other trials free from crawling and pinholing, but as they had the same Al_2O_3 and SiO_2 equivalents as those here represented, they were not figured out.

It was observed, also, that when the Al_2O_3 exceeds .55 equivalents, the glaze loses the *clear white* color and takes on a *grayish white* tint.

A Bristol glaze without any equivalents of clay, strange to say, has not the fusibility of those in which .05 equivalents of clay is used, as will be seen by the following:

TABLE III.

No.	K_2O	ZnO	CaO	Al_2O_3	SiO_2	
167	0.5	0.4	0.1	0.5	3.00	
168	0.5	0.4	0.1	0.5	3.25	All Al_2O_3
169	0.5	0.4	0.1	0.5	3.50	derived
170	0.5	0.4	0.1	0.5	3.75	from Spar
171	0.5	0.4	0.1	0.5	4.00	

TABLE IV.

No.	K_2O	ZnO	CaO	Al_2O_3	SiO_2	
172	0.5	0.4	0.1	0.55	3.00	.05 Al_2O_3
173	0.5	0.4	0.1	0.55	3.25	derived
174	0.5	0.4	0.1	0.55	3.50	from Clay,
175	0.5	0.4	0.1	0.55	3.75	balance
176	0.5	0.4	0.1	0.55	4.00	from Spar

This being a surprise, the samples are submitted for inspection. Those containing the clay are very distinctly better than those without it.

In the Bristol glaze used the most extensively in the Muskingum Valley district of Ohio, the equivalent of clay averages about .14, the glaze maturing at cone 8 to 9.

III. K_2O in White Bristol Glazes.

Potash is generally the only alkali flux used in Bristol glazes. Soda is sometimes introduced by the use of soda spar or ground glass, but these materials are seldom used. The soda introduced by the small amount of borax used in some cases, is too small to exert any important influence.

In feldspar, the stoneware potter finds the potash in the best and cheapest form for his use.

The practical limitations of the use of feldspar is governed on the one hand by the amount of Al_2O_3 permissible in the formula, and by the solvent action of the potash upon ZnO ; and on the other hand by the potash required to flux the glaze to a bright gloss at the heat used.

Lead, as a flux in a white Bristol glaze, is not permissible, not only because of its poisonous character, but because of its great solvent action upon ZnO.

The empirical experimenter in increasing or decreasing the fusibility of his Bristol glaze generally attempts to merely raise or lower the percentage amount of feldspar. In some cases, such a course of precedure would bring the desired results. But through chemistry we learn the limits of such variations.

From the formulæ having .55 equivalents of Al_2O_3, which was found to be the maximum that could be worked with safety, the following were selected as being the best :

TABLE V.

No.	Equivalents of the Ingredients.					Oxygen Ratio	Silica Alumina Ratio
	K_2O	ZnO	CaO	Al_2O_3	SiO_2		
172	0.5	0.4	0.1	0.55	3.10	2.34	5.63
173	0.5	0.4	0.1	0.55	3.25	2.45	5.90
174	0.5	0.4	0.1	0.55	3.50	2.64	6.36
175	0.5	0.4	0.1	0.55	4.00	3.07	7.27
176	0.5	0.4	0.1	0.55	4.00	3.07	7.27
199	0.5	0.4	0.1	0.55	4.00	3.07	7.27
231	0.5	0.4	0.1	0.55	3.25	2.45	5.90

As each of the trials in this table was weighed, ground and applied independent of any other, all possibility of an error influencing each one alike is eliminated. Each stands for itself.

It is noted that .5 K_2O is found necessary to bring these glazes to a good maturity at cone 5 to 6, the heat at which all of the trials were burned.

To harden the glaze, lower the K_2O and increase the CaO, but do not alter the Al_2O_3.

IV. ZnO in White Bristol Glazes.

Zinc has a double mission in a Bristol glaze, acting both as a flux and an opacifier. Other than SnO_2, it is the best opacifying element known to the potter. It is a good flux in lead glazes, adding brilliancy to colors. It is also a good flux in Bristol glazes, making a more fusible RO combination with K_2O and CaO, than would K_2O and CaO alone.

It is astonishing to many that ZnO in some Bristol glaze formulæ does not act as an opacifier, but is completely dissolved, leaving the glazes perfectly clear.

Two glazes showing this are here quoted:

TABLE VI.

No.	K_2O	ZnO	CaO	Al_2O_3	SiO_2	
425	.45	.40	.15	.60	3.25	White
466	.55	.35	.10	.45	2.80	Clear

All the glazes that were either clear or but slightly opaque, were selected and tabulated as follows:

TABLE VII.

No.	K_2O	ZnO	CaO	Al_2O_3	SiO_2	Oxygen Ratio	Silica Alumina Ratio
105	0.40	0.3	0.3	0.45	3.00	2.55	6.66
106	0.45	0.3	0.25	0.50	3.50	2.80	7.00
107	0.50	0.3	0.20	0.55	4.00	3.01	7.27
108	0.40	0.35	0.25	0.45	3.00	2.55	6.66
109	0.45	0.35	0.20	0.50	3.50	2.80	7.00
110	0.50	0.35	0.15	0.55	4.00	3.01	7.27
115	0.40	0.35	0.25	0.50	4.00	3.20	8.00
458	0.30	0.35	0.35	0.40	2.50	2.27	6.25
459	0.325	0.35	0.325	0.425	2.65	2.30	6.33
461	0.375	0.35	0.275	0.475	2.95	2.43	6.20
460	0.350	0.35	0.300	0.45	2.80	2.38	6.22
462	0.400	0.35	0.25	0.500	3.10	2.48	6.20

It is noted that, irrespective of the equivalent amount of the other elements, the resultant glaze is either clear, or nearly so, when the ZnO is .35 equivalent or less.

To note the effect of the use of more than .4 ZnO, the following were compared:

TABLE VIII.

No.	K_2O	ZnO	CaO	Al_2O_3	SiO_2	Oxygen Ratio	Silica Alumina Ratio
117	0.40	0.45	0.15	0.50	4.00	3.20	8.00
118	0.40	0.50	0.10	0.50	4.00	3.20	8.00
424	0.40	0.45	0.15	0.55	2.95	2.22	5.36

Of these, 117 is very good except that it is not perfectly matured. It showed no evidence of crawling. The other two crawled.

It is safe to assume, then, that when the equivalent of Al_2O_3 is 0.5, 0.45 equivalent of ZnO can be safely used, but with 0.55 equivalent of Al_2O_3 not more than 0.4 equivalent of ZnO can be used.

To zinc, many ascribe all the responsibility for the manifestations of crawling, but we have not found that to be the case. ZnO and Al_2O_3 alike are responsible and their

workable limits have here been found to be between 0.50 to 0.55 equivalent Al_2O_3 and 0.45 to 0.40 equivalent of ZnO. When the Al_2O_3 is high, the ZnO should be low, and vice versa.

V. CaO in White Bristol Glazes.

CaO is added as the third RO element. It acts in most cases as a flux, but in some it acts as an opacifier also, or at least adds to the opacity of the glaze.

CaO is an alkaline earth, practically infusible by itself, but in a silicate mixture it is readily soluble with a lead flux, and at higher heats, with the alkali fluxes.

It is used in the compounding of a Bristol glaze in the form of ordinary whiting. In some cases, it is derived also from CaF_2, and $Ca_2(PO_4)_2$, but these cases are rare.

The writer has made no experiments with $Ca_2(PO_4)_2$ as a source of CaO but knows of instances where it is used. It is said to add opacity to the glaze.

Fluorspar is an ingredient that needs to be added very cautiously. Its specific weight makes it a troublesome factor in keeping the glaze mixture homogenous in the dipping tubs.

The following trials will show to some extent its chemical action :

TABLE IX.

No.	K_2O	ZnO	CaO	Al_2O_3	SiO_2
562	0.55	0.35	$\left\{\begin{matrix}0.10\ CaF_2\\0\ 00\ CaCO_3\end{matrix}\right\}$	0.65	3.75
563	0.55	0.30	$\left\{\begin{matrix}0.15\ CaF_2\\0\ 00\ CaCO_3\end{matrix}\right\}$	0.65	3.75
564	0.55	0.35	$\left\{\begin{matrix}0.05\ CaF_2\\0.05\ CaCO_3\end{matrix}\right\}$	0.66	3.75
565	0.55	0.30	$\left\{\begin{matrix}0.05\ CaF_2\\0.10\ CaCO_3\end{matrix}\right\}$	0.65	3.75
566	0.55	0.30	$\left\{\begin{matrix}0.10\ CaF_2\\0.05\ CaCO_3\end{matrix}\right\}$	0.65	3.75
567	0.45	0.40	$\left\{\begin{matrix}0.05\ CaF_2\\0.10\ CaCO_3\end{matrix}\right\}$	0.60	3.25
568	0.45	0.40	$\left\{\begin{matrix}0.10\ CaF_2\\0.05\ CaCO_3\end{matrix}\right\}$	0.60	3.25

As to color, these trials are whiter and glossier than were those of similar composition, but in which all the CaO was obtained from $CaCO_3$.

Samples of these glazes were so placed as to receive a soft and a hard burn. In the softer burned samples, the pinholes, while distinct, are not so numerous as those on the harder burned samples. This same action of CaF_2 was noticed in vitreous tile bodies.

These trials would indicate that 0.05 equivalent of CaF_2 is the maximum that can be used in these glazes, and that for higher heats (cone 7 and up) its use in vitreous or fusible ceramic mixtures is not permissible.

It is to be noted also, that even with the high equivalent of Al_2O_3 these trials show no tendency to crawling.

The glazes given above contained 0.01 equivalent of of borax. The following glaze was made up without borax as follows:

.25	Eqv.	Feldspar.
.20	"	Common Glass.
.05	"	Whiting.
.25	"	Fluorspar.
.15	"	Magnesia.
.10	"	Zinc Oxide.
.10	"	Clay.
.30	"	Flint.

The formula thus produced is:

$$\left.\begin{array}{l} 0.25\ K_2O \\ 0.10\ Na_2O \\ 0.40\ CaO \\ 0.15\ MgO \\ 0.10\ ZnO \end{array}\right\} \quad 0.35\ Al_2O_3 \quad 2.5\ SiO_2$$

This glaze was burned in the open kiln at cone 8. It did not pinhole in the least, and even with the low ZnO and Al_2O_3, was a fair white Bristol glaze.

VI. SiO_2 in White Bristol Glaze.

SiO_2, as an acid, has the same functions in a Bristol glaze as in a lead glaze. However, as Bristol glazes are not designed to flow, as are the lead and boracic glazes, but rather to be only thoroughly fused to a viscous paste, the acid does not have quite the same influence. Indeed, it will be seen that the best Bristol glazes have a lower proportion of Al_2O_3 to SiO_2 than do the ordinary lead glazes.

While SiO_2 is almost infusible by itself, it is often the case that a glaze is too refractory because of its low acidity, and to soften it, more SiO_2 must be added. The converse is likewise true.

As will be seen by the following formulæ of Bristol glazes known to be in use in factories in different parts of the country, consequently on different clays, the best ratio for alumina to silica is between 1:5 and 1:7:

TABLE X.

FORMULÆ	Salts added to prevent crawling	Cone to which Glaze is Fired	Silica Alumina Ratio
$\left.\begin{matrix}0.407\ K_2O\\0.194\ CaO\\0.399\ ZnO\end{matrix}\right\}$ $0.507\ Al_2O_3$ $\left\{2.857\ SiO_2\right.$		5-6	5.63
$\left.\begin{matrix}0.377\ K_2O\\0.180\ CaO\\0.444\ ZnO\end{matrix}\right\}$ $0.516\ Al_2O_3$ $\left\{2.84\ SiO_2\right.$	0.015 Borax	8	5.5
$\left.\begin{matrix}0.450\ K_2O\\0.150\ CaO\\0.400\ ZnO\end{matrix}\right\}$ $0.6\ Al_2O_3$ $\left\{3.25\ SiO_2\right.$	0.01 Borax	5-6	5.4
$\left.\begin{matrix}0.327\ K_2O\\0.300\ CaO\\0.370\ ZnO\end{matrix}\right\}$ $0.366\ Al_2O_3$ $\left\{2.54\ SiO_2\right.$	3% Borax	6	6.9
$\left.\begin{matrix}0.300\ K_2O\\0.200\ CaO\\0.500\ ZnO\end{matrix}\right\}$ $0.5\ Al_2O_3$ $\left\{4.00\ SiO_2\right.$	.05 Boracic Acid	10-12	8
$\left.\begin{matrix}0.224\ K_2O\\0.388\ CaO\\0.386\ ZnO\end{matrix}\right\}$ $0.3567 Al_2O_3$ $\left\{3.00\ SiO_2\right.$		7	8.4

Having found that for the conditions under which the trials quoted were made, the K_2O, ZnO and CaO work best when in the proportions respectively of 5:4:1 equivalents, with Al_2O_3 at 0.55 and a silica-alumina ratio of about 1:6, then the following formula may be regarded as the type or standard to be used under like conditions:

$$\left.\begin{matrix}0.5\ K_2O\\0.4\ ZnO\\0.1\ CaO\end{matrix}\right\}\ 0.55\ Al_2O_3\ \left\{3\ 30\ SiO_2\right.$$

which will develop into a good white glaze at cone 6.

VII. Common Defects in White Bristol Glaze.

I. Crawling.

Crawling may due to any one of the following causes or to the combined inflnence of any two or more of the conditions, even though they may be present in but a slight degree.

A. Too high in clay, or Al_2O_3

B. Too high in ZnO

C. Too thickly dipped

D. Dusty ware

E. Sweating in drying, or early stages of the burning.

"A" and "B" have been discussed.

"C" is obvious to those who have ever coated green ware with another clay mixture.

"D", while it does not receive much attention from the average stoneware potter, is, nevertheless, the cause of much imperfect ware. Electrical insulating companies who make dry press ware have this trouble to a larger entent than do the stoneware companies.

"E" is better seen by the following citation:

For economy of kiln space, and convenience as well, coffee pot lids were often placed between kettles after having been dipped, and hacked in bungs of from 20 to 25 each. The kettles and lids contained such moisture as was absorbed in dipping. These bungs were left on the open drying floor for three or more days. The bungs were then carried intact to the kiln.

It was observed that on over 80 per cent. of those lids, the glaze would be peeled in places and in some cases slipped off the lid entirely. That same glaze under normal conditions of drying, worked beautifully, having very little crawling.

The crawling in this case was obviously caused by the thorough sweating these lids must have been subjected to, being between the crocks where no ventilation was possible.

It is a fact that in a steam dryer with fair ventilation, tile containing from 6 to 10 per cent. of moisture when

placed within it, will sweat until they appear to be very wet, after having been there 24 hours.

The case just cited, while an extreme case, illustrates the effect which too little draft in the "drying off" stage of burning will have.

Most stoneware potters insist upon "keeping the kiln hot", that is not to allow them to stand longer between the burnings than necessary to draw and set. It is the experience of potters, known to the writer, that if the kiln is cool when set, crawled glaze can be depended upon.

This is obviously another case of sweating. The kilns have drawn moisture, which with the moisture from the ware, causes sufficient steam to thoroughly sweat the ware.

As an antidote for crawling, some soluble compound such as $Na_2B_4O_7$ or Na_2CO_3 and Plaster Paris slop are used. To what the counteracting effect of these compounds may be due, is not positively known. Some contend that in drying the soluble salts crystalize, so interlocking themselves as to bind the whole into a coating that will not be apt to crawl.

II. Pinholes.

Pinholes are more often due to imperfect finishing of the ware. Small cavities left in the surface of the ware, become filled with air when the piece is dipped. The air is expelled, blowing a hole through the glaze that has covered the cavity; the result being a pinhole in the finished product.

III. Dryness.

Dryness may be caused by two conditions.

First. By too rapid raising of the heat in the early part of the burning.

Second. By too low or too high SiO_2 as in the last formula given as being known to be in use.

IV. Dusting

After the ware has dried, it is rubbed by the hands and clothes of the kiln setter and if the glaze is too dry, enough will be rubbed off to cause defective ware.

Dusting is prevented by the use of Ball clay in place of China clay or $Na_2B_4O_7$ in place of plaster slop, or use the plaster paris before it has had time to harden.

DISCUSSION.

Mr. Otto Hensel: Last year there were some experiments presented here regarding the use of magnesia as a flux, but no special attention was called to the value of magnesia as to other properties desired in a glaze, such as prevention of crazing and preservation of color. If anything was said on this point, it was mentioned incidentally, but it was not stated that magnesia is more valuable than lime in making a glaze having a greater range of use. In Germany they are beginning to pay more attention to the value of magnesia than they did before. As regards magnesia in clays, from another aspect, Dr. Mäckler states in a technical periodical, that he has subjected some fireproof terra-cotta lumber to chemical analysis. These particular hollow blocks are imported into northern Germany from southern Europe, and are in great favor because they have very thin walls and are nevertheless quite true in shape. He inclines to the belief that their high content of magnesia, estimated at about 9 per cent. carbonate of magnesia in the raw state, gives properties to the clay, such as lime alone will not furnish. He announces that he is going to make a further report on the effects of magnesia. I have noticed that clays in which magnesia is as high the lime are very valuable in holding up their shape in firing, and are perhaps of better quality when burned than if they had been lime in place of the magnesia present.

Professor Orton: Mr. President, I want to say, in corroboration of what Mr. Hensel has called attention to, viz: that the presence of magnesia may be a source of peculiar value to the potter, that I made a series of tests in the way of regular class work, in which we attempted to make a slip like the Albany, beginning with common red shale as a base, and adding those ingredients which the shale did not have in itself. It was not intended as a practical process, because it is cheaper to buy Albany slip than to make it; but it occurred to me as a good problem in the way of drill in the preparation of ceramic mixtures. So we proceeded to alter the red clay to make it do what Albany slip would do as nearly

as we could. In that series of tests, which were only moderately successful, we used whiting to supply the lime and, incidentally magnesia. We construed the lime and magnesia as equal and used lime in place of magnesia; and we were constantly troubled to get anything like the desired color effects where the iron used was merely equal to that in the Albany Slip. My class in experimental work is repeating the work which we did several years ago, with a different clay. We are taking red Bedford shale which is better suited because of more alkalies and more iron; and we are doctoring this red shale into as close an approximation of Albany slip as we can, but we are using dolomite as a source of lime. While we have no results as yet to bring forth, I believe we are rather in the way of progress there, because I believe that magnesia does have a different effect on the color of iron; or, rather, it fails to mask the effect of iron, as lime alone does.

I want to say that this paper has been a surprise to me. Mr. Purdy has been changing his location from Ohio to Illinois, and the paper has been prepared in the last three weeks, in intervals of moving. He has put together more concrete information on the subject of stoneware glazes than I have seen in any one place before. And, further, the results he exploits, while not prepared, perhaps, in the way of a regular series, beginning with the changing values of one element at a time, are a large number of them glazes in actual use in representative stoneware factories at the present time, and gathered by him from a wide knowledge among stoneware men themselves; and I submit that when the paper is put out in printed form, it will be a compendium for stoneware men which they should be exceedingly glad to get, if they are wise. Furthermore, I believe that the same class of glazes are capable of a wide extension in use by enameled brick men. I believe it is true that there is no cheaper glaze with which to coat an architectural product than those of this general lime; therefore, to enamel brick men and terra-cotta men, I think this paper is of very substantial value.

Mr. Burt: My attention was called some time ago to the fact that a high content of zinc in a glaze appeared to render the glaze less acid proof. Four-tenths equivalents of ZnO is rather a high content. Have any of the members experience enough to say whether that amount does carry with it some danger as to the stability of the glaze, as to being acid proof?

Mr. Arthur S. Watts: I have had a little experience in that line. I used for four-tenths of zinc on a glaze for porcelain, fired at cone twelve, single burn for body and glaze. It was repeatedly tested with acid, and never showed any effect of attack. Of course, the temperature used was high. Whether at a lower temperature like ordinary stoneware heat, it would be affected, I do not know.

NOTE ON FRITTING.

BY

STANLEY G. BURT, CINCINNATI, OHIO.

One of the first things I was told on entering the pottery business, was that fritting reduced the contraction of a glaze, and therefore tended to stop craze. I have seen this statement printed many times since. It sounds very plausible. Crazing is undoubtedly due to an excessive contraction of the glaze. Then, if fritting reduces contraction, as it undoubtedly does, why doesn't it stop crazing? I quote from a recently published article on pottery:

"The preparation of the glaze is quite as important, for it is composed of materials subject to great contraction, namely, quartz, feldspar, paris white, borax and a little lead. These, with the exception of the latter article, are fritted or melted in an oven till they run like molasses, they then harden and are crushed and ground in water. Having lost much of their contractility, they are now ready to coat the ware and will fuse and harden on the biscuit without crazing."

As I said in my paper last year, we have in the pottery business two distinct contractions which I called permanent contraction or shrinkage, and constant contraction. If we fire a piece of clay until it gradually approaches fusion, the pores close and we say the clay shrinks. This is permanent contraction. When once fired it can never go back to its original size. Now, if the fired piece is heated it will expand, and on cooling will contract to its usual size. This I call constant expansion and contraction; it is going on all the time, and for the same degree of heat is a constant quantity.

Much the same thing occurs in fritting a glaze; it loses its water of crystallization, carbonic gas, etc.; it fuses, the

pores close, and we have permanent contraction: that is, shrinkage; It has undoubtedly undergone a great permanent contraction, but what has this to do with the coefficient of its constant contraction? If we melt a glaze mix on the inside of a crucible, and call it a fritt, how is it different from the same mix fired at the same time on the outside of the crucible, and called a glaze?

So if we take a glaze mix and fritt it, this mix fuses and contracts; but this is merely permanent contraction, which, as explained, may have no effect whatever on the final coefficient of the glaze, so that a fritted glaze may craze as well as a raw glaze.

In statements like this, that have been handed down from generation to generation, there is generally some basis of fact, and I believe it is undoubtedly true that fritted glaze is less liable to craze than a so-called raw glaze. But, the reasons for this fact are entirely different from those assigned above.

Leaving aside the fact that boracic acid, one of the best means for eliminating craze, that is reducing the coefficient of the glaze, can only be used in a fritted glaze, and that almost all fritted glazes contain it. Let the same glaze be tested raw and fritted, and I think the fritted sample would undoubtedly show the lower coefficient.

A glaze is a chemical combination. All such combinations take more or less time for their completion. The perfect formation of a glaze takes quite an appreciable length of time. We do not, in firing, rush our kiln up to a maximum heat and then stop. We either approach gradually, or else hold the kiln at its full heat in order to allow time for the glaze to complete its chemical combination, or, as we say, its fusion. An under-fired glaze shows undissolved particles in suspension, but how is it with an over-fired glaze? In this case, having completely combined all the ingredients of the glaze mix, it begins to dissolve those of the body. Of the body ingredient readily taken into solution, flint is the chief, and this flint, taken from the body, reduces the glaze coefficient.

With a fritted glaze the chemical combination has already been completed, so that it fuses much more readily and starts at once, as it were, to take up flint from the body. So in the same interval of time, it will be able to take up much more than the raw glaze, and its coefficient will be brought lower and the danger of craze much reduced.

I feel it is peculiarily the duty of our society to explain pottery dogmas like this, and to make a clear understanding of the facts open to those who care to know them.

OPPORTUNITIES FOR RESEARCH IN A FACTORY.

BY

CHARLES F. BINNS, ALFRED, N. Y.

The common acceptation of the term "research" is, an original investigation which tends to increase the knowledge of mankind, but, while not neglecting this wide definition, the term may be employed as expressing a pursuit of information which shall increase one's own knowledge, even though others may have trodden the same path.

In this sense every experimenter is engaged in research and is adding to his personal store of facts, even though he discovers nothing new. At the same time, even the most modest research must be more than a mere trying of recipes. There are in the ranks of our clay workers, hundreds of men whose love for a recipe passes the love of women, but who never get further than the recipes can take them. The experimenting that is needed is along the line of testing the influence of various minerals and chemicals upon each other under differing conditions, and thus preparing the way for new combinations and perhaps important results.

But the question will be raised, "suppose a superintendent or foreman be successful in some discovery, of what use will it be to him, and will he be ready to impart his knowledge?"

I submit that the question is premature. The spirit of research slumbers in the minds of many. Perhaps it is starved by the exigent demands of other faculties or it may be drugged into quietude by pride or suspicion, for even clay-workers are human and have human failings; but let it be awakened, let an occasional hour be stolen from play and the draught of inquiry be tasted. Then shall the spirit of research awake and arise and difficulties will disappear as dew before the morning sun.

It has often been remarked that the nature of the work to be performed, measures the amount of time available for the performance. No young man, for example, ever pleaded want of time as an excuse for not calling on his lady love, nor will pressure of other work ever keep the devoted experimenter away from his pestle and mortar.

It is quite possible that no material gain — no money gain — may follow new discoveries or new applications of old rules, but he who gains knowledge gains power, and every success, even if unrecognized, places a man just so much further towards his goal. As to the imparting of knowledge, a clay-worker cannot make many trials, without feeling the need of some congenial spirit with whom to discuss the results, and a mutual interchange soon follows.

The common idea of the practical man — why should that expression not be changed? We are all practical men; the term seems, by common consent to belong to the man who has nothing but his practical qualifications to stand upon, no science, in other words — is that investigation is the prerogative of the scientific man, and the college professor. They are not practical, and have nothing to do but weigh and mix. To state that professors have no time for research, would be to controvert my own argument; but this I will say — after wrestling with classes of elementary students and patiently covering the familiar ground of formula and reaction, it is an immense relief to turn to the laboratory table and pursue some inquiry, thought out perhaps, in theory, during wakeful nights or such spare moments as may have been secured.

The experimenter in the factory has one great and far reaching advantage, viz: His kilns are being regularly fired. His trials for the most part are made at the established temperatures of his glost and biscuit ovens, and all he has to do when the trial is prepared is to hand it on to the kilnman.

Those on the other hand, who are popularly supposed to be able to experiment more easily, have to provide themselves with even the simplest appliances—to make their own saggers, to do their own potting, dipping and placing and to fire their own kilns.

The necessary tools for factory research are few and simple. A dozen jars, a pestle and mortar, a sheet of plate glass, a muller, a palette knife, a sponge and a couple of bowls with a good pair of scales make up the outfit. It is best to discard at once the use of pounds and ounces. A set of weighs from 100 grams to .1 gram will permit trials to be made in percentage proportions and the transitions to larger weights is easy. It is perhaps hardly necessary to point out the importance of system in trial making, yet a potter's table, covered with trials of every shape and size, with no distinguishing mark but an arbitrary sign, is familiar.

Clay trials should be made in a uniform mould or die, according to the ceramic field explored; the length should be upward of 10 cm. to allow that measure to be accurately marked as a test of shrinkage. The heat of the oven should be marked, either by anticipation in the clay or afterwards in color. A series number and a specific number should be given, and accurate notes kept. It often happens that a number of trials are thrown away after a few months, simply because the man who made them has forgotten what they were.

When fired, the briquette or tile can be glazed or enameled over one-half of its surface to allow a comparison between glazed and unglazed surfaces.

A corner of the mixing room can generally be set apart for this experimental work and to this spot, as to a haven of refuge after a stormy sea, the harassed superintendent can retire for a moment's breathing space.

It may not be out of place here to suggest some of the problems which may with profit be investigated by the practical potter. In the white ware industry the employment of native materials is an important question. A great deal of English kaolin is being used, and the only reason is that it has always has been so—a reason that might perhaps satisfy an Englishman, but which seems to be out of harmony with American ideas. The rational analysis of the respective clays can always be obtained, and the substitution becomes a matter of accurate adjustment. I am acquainted with potters who pride themselves on using nothing but

American clays, and yet there are others, making similar wares, who claim that these clays are not good enough.

Flint is a material about which little is known. Mr. Burt's paper of last year opened up the subject, and there is room for an exhaustive inquiry as to size of grain, shape of grain, dry or wet grinding and color. In glazes there is scope for unlimited research. Theoretically, many are satisfied as to the cause and cure of crazing, but how many have conducted a systematic series of experiments to support or disprove the theories? The best glaze for under glaze colors is a subject about which everybody wants information, and the best way to get it is to dig it out for one's self. Mr. Mayer gave an important contribution on this point at our first meeting, but the investigation should be pursued at other temperatures than that used by him.

In coarser wares, the problems are at least as numerous and important. Let me instance a few of them: The best structure and composition of a fire-brick to withstand fire and weight; the influence of grog, its proper composition and size of grain; the profitable production of enameled brick; the manufacture of blue paving brick; the successful manufacturer of electric conduits; the resistance of clay ware to electric pressure, and so forth.

No man can afford to stand still; others will not wait for him; but, by thoughtful work, it is possible for everyone to help towards the success of the industry which is his life's vocation.

The facilities of the factory are not to be despised. Even though there be less time for thought and research, less time is necessary for the worker who has a factory at his back can outpace him who has no such help.

If we could persuade each of our factory superintendents to be, even in a small way, an experimenter, and to tell of his work, a vast amount of useful ceramic information would soon be compiled to the great advantage of our industry and the benefit of every clay worker in the land.

THE COMPOSITION OF PORCELAIN FOR ELECTRICAL PURPOSES.

BY

ARTHUR S. WATTS, FINDLAY, OHIO.

Connection with and interest in the porcelain insulator business has impressed me with the fact that while the products of some companies stand very high tests and seem in every way ideal insulators, the products of some other companies are well nigh worthless.

What is the cause? What are the essential constituents of an electrical insulating porcelain?

Those who know, if any know, do not seem disposed to distribute the information. Hence, I have decided to pursue such a line of investigation as will determine, if possible, what these essentials are.

I give you my work along this line. The results as I find them may be disproven by later investigation, but if only a foundation for the later work may be laid at this time, I will consider myself well repaid for the time invested.

General Considerations on Electrical Porcelain Bodies.

I quote as follows, from Herzog and Feldman on the subject of electrical porcelain: "A porcelain mass will be the more resistant, the higher the proportion of kaolin and feldspar; also the finer the grain of the kaolin used, the higher will be the maturing point of the porcelain produced."

The leading materials used in porcelain manufacture are certain kinds of kaolin, which are very slightly plastic, quartz and feldspar. Of course ordinary feldspar displays basic properties in the fire, uniting with silica to form silicates, thus producing an intimate mixture of all silicates. Therefore, the contents of kaolin must be in a definite ratio to the quartz and feldspar in regard to the insulating properties.

Too much quartz makes the body too little plastic, thus making it difficult to work, and after burning, the ware shows impressions and some warping due to the tendency of the clay substance to the contract.

Too high a content of feldspar makes the body soft and liquid, and increases the tendency to crack.

A body low in feldspar does not produce sufficient vitrification and hence decreases its insulating efficiency.

A porcelain body may shrink 15 to 18 per cent., and it is very important that the exact degree of shrinkage be known. No crazing or shivering is allowable in the glaze used on ware for electrical materials. If the glaze is too infusible the ware will be dull, and if too fusible it is likely to be covered with blisters. Investigation has proven the condemnation of glazes containing metallic oxides to be unfair. Metallic oxides, when used in glazes combine with the silica, forming silicates.

Probably in no line of electrical investigation have greater progress and more varied experiments been made than in the shape and size of electrical insulators. The plain bell which is used for low potentials and which is also practical and satisfactory for alternating currents up to 1000 volts, does not meet the requirements of modern high voltage transmissions.

The first step in the way of improvement was made in 1857 by Borggreve. The product was satisfactory so far as electrical and mechanical requirements were concerned, but failed owing to the fact that the interior space was square, which gave rise to uneven tensions in the body and frequent fractures.

The second step in the way of improvement was the production of a very long insulator having a very narrow cross-section. It was the idea of the inventor to increase the resistance by means of a long arcing distance. The insulator produced was of clear glass and suffered from the contraction and expansion of the iron bolt used to connect it to the cross-arm and which became intensely hot from the sun's rays on the insulator. This condition caused the introduction in 1895 of the double bell insulator of porcelain.

In this, the interior cylindrical part of the insulator is covered by a second bell which prevents the radiation of heat and also the formation of dew.

Up to a tension of 3000 volts, the ordinary double bell 75 mm. wide and 100 mm. high suffices, but above this voltage the question of further improvement arises.

In 1869 Lenoir and Prudhomme obtained a patent for the use of oil in insulator bells. Insulators of this type were used in constructing the famous line between Lauffen and Frankfurt. They proved impractical, as the oil must be replaced frequently and in case of rain it was often replaced by water.

In constructing the Kaiser Wilhelm Canal Line a triple bell insulator without oil was used and proved satisfactory even when exposed to salt spray. This type is now commonly in use for high voltage transmissions.

At first the insulators were glazed and burned resting on the bottom edge of the bell, but the roughness of this edge seemed to cause the collection of drops of water and to prevent this, the insulator is now glazed all over, the glaze removed from the head and the insulator burned inverted. Very recently it has been discovered that by glazing the inside of the insulator in the threaded hole, the insulator is made much more resistant and need not be so thick.

The following table of the Delta Bell Insulator I take from Herzog and Feldman "Electric Lighting Installation:"

Weight of Insulator	Potential Voltage to be Carried	Height	Diameter	Shortest Distance Allowable		
				From Insulator to Nearest Object	Between two Parallel Lines	From Insulator to the Ground
grams		mm	mm	mm	mm	mm
1200	6000	115	145	200	400	190
2500	12000	150	190	260	520	220
4800	25000	170	250	360	720	280
7000	50000	225	250	460	920	370

The weight of the porcelain used in the insulator is not of the greatest importance, but rather, the quality of the porcelain and the kind of glaze.

Manufacturing Processes.

Just here a word regarding the working of porcelain bodies may not be out of place. In Europe, insulators are made by all five of the clay working processes, viz: turning, jollying, pressing, casting and dry pressing. I am familiar with all of these processes except casting, but am not prepared to pass judgment on the superiority of any given process of working, as of course the product and its shape and size would greatly influence the method chosen. Dr. Seger, in his work, shows very conclusively that a semi-dry process, in which the material to be pressed contains the highest per cent. of water allowing of good pressing, gives the densest and strongest body.

Turning of large insulators is done similarly to all clay turning, the product being made mouth up and the top finished when the ware is sufficiently dry to permit of its being inverted. In this class of ware, much trouble is experienced in making the screw-thread for the pin which is to support the insulator. This thread is made by means of a threaded steel tube which is provided with a handle on one end and which is slowly turned in and out. In place of a full steel tube a segment may be used. Automatic boring apparatus is now being applied for this work.

Jollying is now largely replacing turning although it does not insure as dense and uniform a body as the former process.

Pressing is done in molds. The clay is placed in the mold in a lump and by means of a plunger is forced to assume the shape of the inside of the mold for its exterior while the plunger shapes its interior.

Dry pressing produces more exact shapes than any other method. The molds used are of steel and are very expensive. The body must be in such shape that it will not stick to the mold. To obtain it in this condition some factories

use the following process: The clay after drying and being thoroughly pulverized, is placed in wet cement or plaster boxes and allowed to absorb 10 to 20 per cent of moisture. The mass is then sieved thoroughly. Ten kilograms of the body will contain about 1 to 2 litres of water. Of course this proportion must be maintained exactly in order to insure a uniform shrinkage. The molds are sometimes complicated and are often composed of insertions. The piece of ware produced is threaded by means of a screw inserted in the bottom before the clay is introduced and which is screwed out rapidly by means of a crank. The tendency is to make insulators without threads, as this has always been a great source of trouble and loss in manufacture.

Selection of a Standard Porcelain as a Basis for the Experimental Work.

In outlining the work that follows, it seemed necessary to choose some type or standard of porcelain which I could use as a basis from which to map out varying series. The wisest course here seemed to be to procure a large number of standard porcelains, and to obtain from these by comparison the most characteristic type of porcelain now in use.

In compiling the following list of porcelains, I have not stated the present use of the body, but will state that the list includes only practical workable porcelains that have been, or are now, in actual use.

I wish to further state, that in my opinion such a list is valuable as a comparison and not as a basis from which to compound practical porcelains. Acting on Professor Binn's suggestion,* I shall take Al_2O_3 as unity in these formulæ.

* The Birth of English Porcelain, Trans. A. C. S., Vol. III, page 144.

TABLE I.

No.	Chemical Formulæ			Locality
1	.0467 K_2O	1. Al_2O_3	5.976 SiO_2	Japanese Body
2	.1140 K_2O	1. Al_2O_3	4.168 SiO_2	Society of Hal. Belgium
3	.1160 K_2O	1. Al_2O_3	3.75 SiO_2	Plymouth Body
4	.1213 K_2O	1. Al_2O_3	4.32 SiO_2	Lahalleur Vierzon (Heavy)
5	.0707 K_2O .0860 CaO .1567 RO	1. Al_2O_3	3.22 SiO_2	Bristol Body
6	.1622 K_2O	1. Al_2O_3	3.95 SiO_2	Limoges (Fine)
7	.1836 K_2O	1. Al_2O_3	3.98 SiO_2	Limoges (Common)
8	.2020 K_2O	1. Al_2O_3	4.74 SiO_2	Limoges (Figures)
9	.1336 K_2O .0961 CaO .2297 RO	1. Al_2O_3	4.66 SiO_2	Karlsbad Body
10	.2400 K_2O	1. Al_2O_3	5.2 SiO_2	American Body
11	.2450 K_2O	1. Al_2O_3	5.027 SiO_2	Limoges Body
12	.2540 K_2O	1. Al_2O_3	4.51 SiO_2	Limoges (Fine)
13	.2584 K_2O	1. Al_2O_3	5.44 SiO_2	American Body
14	.2770 K_2O	1. Al_2O_3	7.06 SiO_2	Japanese Body
15	.2700 K_2O .0100 CaO .2800 RO	1. Al_2O_3	3.95 SiO_2	Limoges Body (Common)
16	.1635 K_2O .1186 CaO .2821 RO	1. Al_2O_3	4.35 SiO_2	Karlsbad Body
17	.2860 K_2O	1. Al_2O_3	6.05 SiO_2	Berlin Body
18	.3312 K_2O	1. Al_2O_3	4.74 SiO_2	Limoges Body
19	.3330 K_2O .0200 CaO .3530 RO	1. Al_2O_3	4.72 SiO_2	Chinese Body
20	.1290 K_2O .2070 CaO .3360 RO	1. Al_2O_3	4.39 SiO_2	Sevres Body

TABLE I—Continued.

No.	Chemical Formulæ			Locality
21	.1467 K_2O .2017 CaO .3484 RO	1. Al_2O_3	4.07 SiO_2	American Porcelain (Heavy)
22	.3583 K_2O .0014 CaO .0030 PbO .3627 RO	1. Al_2O_3	3.96 SiO_2	English Porcelain
23	.1590 K_2O .2160 CaO .3750 RO	1. Al_2O_3	4.33 SiO_2	American Porcelain (Fine)
24	.2880 K_2O .1255 CaO .4135 RO	1. Al_2O_3	3.7 SiO_2	Limoges Body (Fine)
25	.1776 K_2O .2442 CaO .4218 RO	1. Al_2O_3	4.16 SiO_2	American Body (Medium)
26	.1910 K_2O .2645 CaO .4555 RO	1. Al_2O_3	3.74 SiO_2	American Body (Medium)
27	.4360 K_2O	1. Al_2O_3	4.81 SiO_2	American Body (Fine)
28	.4900 K_2O	1. Al_2O_3	4.0 SiO_2	American Body (Medium)
29	.0960 K_2O .4040 CaO .5000 RO	1. Al_2O_3	3.08 SiO_2	Sevres Body (Heavy)
30	.2240 K_2O .3010 CaO .5250 RO	1. Al_2O_3	5.34 SiO_2	Hache and Pepin (Fine)
31	.0800 K_2O 1.7560 CaO 1 8360 RO	1. Al_2O_3	3.2 SiO_2	English Bone China
32	.2580 K_2O 2.0780 CaO 2.3360 RO	1. Al_2O_3	15.2 SiO_2	Dr. Wall's Body*
33	.2690 K_2O 2.5400 CaO 2.8090 RO	1. Al_2O_3	3.39 SiO_2 1.67 P_2O_5	Modern English Body*

*Trans. A. C. S., Vol. III, Birth of English Porcelain.

TABLE I—Continued.

No.	Chemical Formulæ			Locality
34	.1370 K_2O 2.7370 CaO 2.8740 RO	1. Al_2O_3	4.25 SiO_2 1.09 P_2O_5	Bow Body*
35	.2300 K_2O 5.2000 CaO 5.4300 RO	1. Al_2O_3	7.12 SiO_2 1.5 P_2O_5	Chelsea Body*
36	2.9350 K_2O 3.9040 Na_2O 5.2770 CaO 12.1160 RO	1. Al_2O_3	31.43 SiO_2	Dr. Wall's Body*

At first sight this list seems a hopeless conglomeration, ranging to all extremes, but closer study discloses the fact that, while the RO varies from .0467 in the Japanese to 5.43 in the old English, and from .114 in modern Belgium to 1.84 in modern English ware, the proportion of SiO_2 is comparatively constant. Only in two out of thirty-six cases does the SiO_2 run below 3.7, and in only two cases of modern porcelain does it run over 6.0 SiO_2. The average of the list I find to be between 4. SiO_2 and 4 4 SiO_2, hence I took 4.2 SiO_2 as the standard.

I next chose a standard from the RO. To obtain this by the same method as pursued with the SiO_2 would prove unsatisfactory, since to take an average of the entire list would result in a RO of 1.00, while to take an average of the thirty modern porcelains would give us about 0.3 RO. The first case would give us about a cone 6 product while the second case gives us very nearly the type of an American porcelain maturing at cone 12.

I did not think a choice between such extremes could be satisfactory, so I concluded to make a series covering each extreme and a third about half way between. To this end I started with the three following types:

Series A.	1. RO, 1. Al_2O_3, 4.2 SiO_2	Cone 6 type
Series B.	.5 RO, 1. Al_2O_3, 4.2 SiO_2	Cone 9 type
Series C.	.3 RO, 1. Al_2O_3, 4.2 SiO_2	Cone 12 type

*Trans. A. C. S., Vol. III, Birth of English Porcelain.

Method of Production of the Trial Bodies.

The various porcelains I produced in the following manner:

The two extremes of each set, I weighed out and ground wet in a ball mill. The intermediate numbers I obtained by liquid blending of the extremes. After the blends were thoroughly mixed, I poured them into plaster molds to harden by loss of their water. Of each porcelain body I made the following ware:

2 brickettes made in standard cement,—brickette molds, and having a central cross section of 1 inch in the green state. These were made by the plastic process.

2 cubes of 50 grams weight made also by the plastic process.

2 tiles, 4½ inches x 4 ½ inches, in green state. These were made by the dry-press process.

The material for the dry pressed tile was prepared as follows: The dry body was thoroughly pulverized and was then dampened with water by means of a brush and the hand, thus obtaining a fairly uniform dampness. The damp clay was allowed to stand about two hours and was then put through a twenty-mesh screen and promptly pressed into the desired shape by means of a hand tile press. About 12 to 14 per cent. of water was in the clay when it was pressed.

Upon the various forms made up, I made the following tests:

Electrical resistance test, tensile test, abrasion test, absorption test and shrinkage test.

Preliminary Studies on the Electrical Test.

While no great obstacle lay in the way of the tensile, abrasion, absorption or shrinkage tests, I found a very great one confronting me, when I considered testing the electrical resisting properties of the porcelains. In the first place, I had no idea how much electrical resistance a given thickness of porcelain might display. In the second place, I could only press a tile of one size, viz: 4½ inches x 4½ inches. I saw that I must obtain, if possible, some insulating material in which to imbed the tile and thus

increase the arcing distance of the current, since with 4½ inches arcing distance, I could not use quite 55000 volts without the current arcing around the tile.

In searching for a material to use for the insulating apron referred to, I found that S. P. Thompson, in his treatise. " Electricity and Magnetism," page 310, gives the following table of specific resistances:

TABLE II.

Silver	100.
Copper	96.
Gold	74.
Iron Soft	16.
Dead	8.
German Silver	7.5
Mercury (liquid)	1.6
Glass at 200° C less than	.000,000,001
Gutta percha ——— less than	.000,000,001
Selenium Annealed less than	.000,000,0025
Pure Water at 22° C less than	.000,001

The preceding table of conductivity or resistance, as you may please to call it, indicates that the last four substances: Glass, gutta percha, selenium and pure water are far better insulators than any other substances ready at hand. The idea of using Portland cement, however, suggested itself, and as it seemed plausable that this might be a good insulating material, I proceeded to try it.

To do this, I took a semi-vitrified tile, 4 x 4 x ⅜ inches, and incased it in a slab of Portland cement (Dyckerhoff). The cement was carefully tamped around the tile so that a good attachment might result. I also made several other slabs of cement, both German and American. In these I encased no tiles. All the cement slabs stood six days in water, and were then taken out and carefully dried. I then proceeded to test their resisting properties with poor results. Each and every slab showed only so much electrical resistance as a like thickness of pure air would show, thus proving that the small insulating power displayed by the cement was due to the fact that its thickness held the electrodes apart and made an arc necessary.

I next tested the tile encased in cement. I had also provided myself with the following insulating materials: One sheet window glass; one sheet plate glass; one sheet plate glass; one porcelain tea plate; one tile 4x4x⅜ inches unincased. The results of the test of the above was as follows:

Tile 4x4x⅜ inches, incased in slab of Portland cement, punctured at ..... 17,000 volts.
Tile 4x4x⅜ inches, unincased, punctured ..... 20,250 "
Sheet window glass 6x6x⅛ punctured at..... 40,000 "
Porcelain Tea Plate 6 inches in diameter x ⅛, punctured at..... 49,500 "
Sheet Plate Glass 6x6x¼ stood 60,000 volts and then the current arced around sheet and could not puncture it.

I would state here that the tile incased in cement and the unincased tile were both of the same composition, and as both were porous to a degree, it is to be presumed that the incased tile which had been soaked for six days still retained some moisture when tested, which accounts for its lower puncturing point than was displayed by the unincased tile. The facts brought out by this preliminary test seem about as follows:

First. That Portland cement does not possess any more insulating power than would be displayed by a like thickness of dry air.

Second. That porcelain, if not perfectly vitrified, does not possess any great insulating efficiency, even when perfectly dry.

Third. That glass ranks next and lies between semi-vitrified and vitrified porcelain.

Fourth. That thoroughly vitrified porcelain, even though only ⅛ inch thick, possesses as much insulating strength as is necessary, since 40,000 volts is the highest voltage that can be transmitted without arcing around a 4½ x 4½ inch tile.

Fifth. That plate glass possesses an especially high electrical resisting property.

We know that the composition of glasses has a great influence on their ability to resist electric currents. Also, that the temperature at which they are used is a factor.

The following data were obtained from Widemann on "Electricity," Vol. 1, page 560:

TABLE III.

HEAVY LEAD GLASS		WHITE MIRROR GLASS		GREEN BOTTLE GLASS	
Analysis		*Analysis*		*Analysis*	
K_2O..... 4.0		K_2O..... 3.67		K_2O ... 6.53	
Na_2O... —		Na_2O . 9.48		Na_2O... 8.68	
PbO 67.0		CaO 16.00		CaO 12.55	
SiO_2... 20.0		SiO_2 ... .. 67.80		SiO_2.... 68.02	
100		96.88			
Melting point. 700°C.				Melting point, 1080°C.	
Temp.°C	Resistance.	Temp.°C	Resistance.	Temp.°C	Resistance.
216.	188600.	189.	182200.	170.5	173200.
226.	113160.	200.	109320.	180.4	86600.
234.	75440.	214.	54660.	198.8	34640.
249.	37720.	288.5	27330.	211.0	17320.
269.	18860.	247.	12754.	222.5	10392.
286.	11316.	269.	5466.	250.5	3464.
297.	7544.	299.	1822.	266.5	1732.
312.	3772.	316.5	1093.2	305.5	519.6
326.	1886.	329.	728.8	327.5	259.8
341.	943.	349.	364.4	343.0	173.2

The foregoing tables take mercury as the unit of conductivity, or as having a resistance of 1.

To return to my search for an aproning material to use with my tiles, I found that a gutta-percha plate could not be cemented to the tile for each test and then removed, and to furnish a separate sheet of gutta-percha for each tile would mean entirely too great an expense. Selenium also was out of the question owing to its cost. I concluded, however, to try sulphur, which is a very similar material to selenium, and to do this I took two bottomless flasks and by means of sulphur in the melted state I cemented these two flasks to two tiles. I also cast two large plates of sulphur with tiles imbedded in their centers. One tile was completely imbedded leaving only a hole ½ inch in diameter on each side to admit the electrode. The second tile was only imbedded on one side in the sulphur, the other side was left exposed. There was a one half inch hole on the imbedded

side of the tile to admit the eloctrode. The tiles were vitrified. I also cast a plate of sulphur 6x6x½ inches. The results of the electrical test on sulphur was as follows:

The plate containing the half imbedded slab stood about 58.000 volts and then the current arced through the sulphur. The plate containing the completely imbedded tile stood about the same, the current going around the tile through the sulphur. The tiles cemented to the flasks were not satisfactory since the current found its way between the glass and the sulphur. The slab of pure sulphur ½ inch thick stood about 13.500 volts and then punctured. On its being punctured the slab caught fire from the spark.

I felt satisfied that at least none of the materials available could be successfully used as an aproning material so I discarded the idea of aproning my tiles, and reduced the thickness of the pieces to be tested electrically to an amount which would puncture before the current would arc around the tile.

Formulæ of the Porcelain Bodies Made.

I have already given the formulæ of the three porcelains which I selected as fairly illustrating the types now in actual use. Taking each type as a basis, I made three separate sub-series of bodies as follows:

I. Maintaining RO and SiO_2 constant and varying the proportion of Al_2O_3.

II. Maintaining the Al_2O_3 to SiO_2 constant and varying the RO in kind but not in quantity.

III. Maintaining the RO and Al_2O_3 constant and varying the proportion of SiO_2.

Each sub-series consisted of a set of five porcelains. In this way, I expected to cover the ground most completely.

Following I give the detailed chemical formulæ of the various porcelains included in this investigation:

SERIES A—CONE 6 TYPE.

In Series A I use Dr. Seger's RO, viz.: $\left.\begin{matrix} .3\ K_2O \\ .7\ CaO \end{matrix}\right\}$

Sub-Series A-I.

A-I-1	.3 K_2O / .7 CaO	.7 Al_2O_3	4.2 SiO_2
A-I-2	.3 K_2O / .7 CaO	.8 Al_2O_3	4.2 SiO_2
A-I-3	.3 K_2O / .7 CaO	.9 Al_2O_3	4.2 SiO_2
A-I-4	.3 K_2O / .7 CaO	1.0 Al_2O_3	4.2 SiO_2
A-I-5	.3 K_2O / .7 CaO	1.1 Al_2O_3	4.2 SiO_2

*Series A-II.**

A-II-1	.3 K_2O / .7 CaO	1. Al_2O_3	4.2 SiO_2
A-II-2	.4 K_2O / .6 CaO	1. Al_2O_3	4.35 SiO_2
A-II-3	.5 K_2O / .5 CaO	1. Al_2O_3	4.5 SiO_2
A II-4	.6 K_2O / .4 CaO	1. Al_2O3	4.65 SiO_2
A-II-5	.7 K_2O / .3 CaO	1. Al_2O_3	4.8 SiO_2

Series A-III.

A-III-1	.3 K_2O / .7 CaO	1. Al_2O_3	3.2 SiO_2
A-III-2	.3 K_2O / .7 CaO	1. Al_2O_3	4.2 SiO_2
A-III-3	.3 K_2O / .7 CaO	1. Al_2O_3	5.2 SiO_2
A-III-4	.3 K_2O / .7 CaO	1. Al_2O_3	6.2 SiO_2
A-III-5	.3 K_2O / .7 CaO	1. Al_2O_3	7.2 SiO_2

SERIES B — CONE 9 TYPE.

Series B-I.

B-I-1	.3 K_2O / .2 CaO	.7 Al_2O_3	4.2 SiO_2
B-I-2	.3 K_2O / .2 CaO	.8 Al_2O_3	4.2 SiO_2

* In Series A-II it was necessary to vary the SiO_2 content slightly in order to introduce the additional K_2O as feldspar.

B-I-3	.3 K_2O .2 CaO	.9 Al_2O_3	4.2 SiO_2
B-I-4	.3 K_2O .2 CaO	1.0 Al_2O_3	4.2 SiO_2
B-I-5	.3 K_2O .2 CaO	1.1 Al_2O_3	4.2 SiO_2

Series B-II.

B-II-1	.5 CaO	1. Al_2O_3	4.2 SiO_2
B-II-2	.375 CaO .125 K_2O	1. Al_2O_3	4.2 SiO_2
B-II-3	.25 CaO .25 K_2O	1. Al_2O_3	4.2 SiO_2
B-II-4	.125 CaO .375 K_2O	1. Al_2O_3	4.2 SiO_2
B-II-5	.5 K_2O	1. Al_2O_3	4.2 SiO_2

Series B-III.

B-III-1	.3 K_2O .2 CaO	1. Al_2O_3	3.2 SiO_2
B-III-2	.3 K_2O .2 CaO	1. Al_2O_3	4.2 SiO_2
B-III-3	.3 K_2O .2 CaO	1. Al_2O_3	5.2 SiO_2
B-III-4	.3 K_2O .2 CaO	1. Al_2O_3	6.2 SiO_2
B-III-5	.3 K_2O .2 CaO	1. Al_2O_3	7.2 SiO_2

SERIES C—CONE 12 TYPE.

Series C-I.

C-I-1	.2 K_2O .1 CaO	.7 Al_2O_3	4.2 SiO_2
C-I-2	.2 K_2O .1 CaO	.8 Al_2O_3	4.2 SiO_2
C-I-3	.2 K_2O .1 CaO	.9 Al_2O_3	4.2 SiO_2
C-I-4	.2 K_2O .1 CaO	1.0 Al_2O_3	4.2 SiO_2
C-I-5	.2 K_2O .1 CaO	1.1 Al_2O_3	4.2 SiO_2

Series C-II.

C-II-1	.3 CaO	1. Al_2O_3 4.2 SiO_2
C-II-2	.225 CaO, .075 K_2O	1. Al_2O_3 4.2 SiO_2
C-II-3	.15 CaO, .15 K_2O	1. Al_2O_3 4.2 SiO_2
C-II-4	.075 CaO, .225 K_2O	1. Al_2O_3 4.2 SiO_2
C-II-5	.3 K_2O	1. Al_2O_3 4.2 SiO_2

NOTE—Owing to a lack of time, no attempt was made to run a C-III Series, but an approximate idea on the variation of silica at this temperature will be obtained by a study of Series C-I.

PRELIMINARY TEST.

I was unwilling to spend the great amount of time and labor on this investigation, without some assurance that the mixtures I proposed to make, as shown by the preceding formulæ, would give me the range of workable porcelains which I expected. I therefore made cones of all the various porcelain bodies to be tested and each series was tested against a standard Seger cone of the temperature to which that series was to be fired. The results of this test were as follows:

Series A—tested against Cone 6.

Specimen A-I-1 shows about the same fusing point as cone 5, hence is useless at this temperature.

Specimen A-I-2 developed into a splendid porcelain of high grade. Translucency is at its maximum, but indications of fusion are apparent.

Specimen A-I-3 is a splendid porcelain with a slight trace of stoniness and good translucency.

Specimen A-I-4 gives a perfectly stony porcelain, but perfectly vitrified and with slight translucency.

Specimen A-I-5 evidently too high in Al_2O_3 for this temperature. Has a dead white surface with no translucency and evidence of porosity.

Specimen A-II-1 is the same as A-I-3 and shows a very similar development.

Specimen A-II-2 is somewhat further developed than A-II-1, but only shows translucency on the edges.

Specimen A-II-3 begins to take on a characteristic porcelain appearance, quite translucent with slight stoniness.

Specimen A-II-4 has about the same degree of development as displayed in A-I-3, good translucency with only slight stoniness.

Specimen A-II-5. We here reach again the high grade porcelain type, all traces of stoniness having disappeared and the surface being self-glazed, as in A-I-2.

Specimen A-III-1 shows a hard dead white surface with no signs of translucency and with indications of porosity.

Specimen A-III-2 same as A-I-4 and A-II-1.

Specimen A-III-3. Slightly improved over A-III-2 in translucency but otherwise unchanged.

Specimen A-III-4 shows fair translucency but is too high grade a porcelain for much strength.

Specimen A-III-5. Good translucency but is semi-glazed, indicating over maturity.

Conclusions on Appearance of Series A.

Series A-I seems to indicate that at this temperature we may expect good porcelains with from .8 to 1.0 Al_2O_3 Below .8 Al_2O_3, we find the body melts out of shape and above 1. Al_2O_3 it does not mature. .8 or .9 Al_2O_3 gives a fine translucent porcelain at cone 6.

Series A-II shows that CaO alone does not produce a porcelain and apparently does not flux materially at this temperature. Evidently, CaO does not produce any translucency, but changes suddenly from the dry to the glassy state. K_2O seems to have done its maximum amount of fluxing, since A-II-5 shows a splendid degree of vitrification and translucency.

Series A-III seems to indicate that an increase of SiO_2 does not affect the appearance of the porcelain to the same degree as do the other two constituents. However, it shows that to obtain a good porcelain, the SiO_2 should be between 4.2 and 6.2 SiO_2, as below 4.2 SiO_2 we get immaturity and above 6.2 SiO_2 we get a weak glassy product.

Series B. Tested Against Cone 9.

Specimen B-I-1 shows about the same degree of development as cone 9, so that its absolute fusing point is too nearly reached to make it a practical porcelain at this temperature.

Specimen B-I-2 is a brilliant, self-glazed porcelain, and has a fine translucence.

Specimen B-I-3 shows a fair degree of translucency and a tendency to stoniness.

Specimen B-I-4 is a stony appearing porcelain with only traces of translucency on edges.

Specimen B-I-5 is a very stony body with a little or no trace of translucency.

Specimen B-II-1 could not properly be called a porcelain. It is a porous, cream-white biscuit,

Specimen B-II-2 displays a marked improvement over B-II-1 in that it is a closer, stonier body, but signs of porosity are still noted.

Specimen B-II-3 seems to be a good stony porcelain, and from all appearances is perfectly vitrified. It displays traces of translucency on all exposed points and has a smooth satiny surface.

Specimen B-II-4 is a fine porcelain, with good translucency and a smooth surface. It still retains some signs of stoniness.

Specimen B-II-5 gives the finest porcelain so far obtained. Perfect translucency without a trace of stoniness and brilliantly self-glazed on all exposed points.

Specimen B-III-1 shows a slightly undermatured porcelain but does not appear porous.

Specimen B-III-2. Same as B-I-4, and shows a similar development.

Specimen B-III-3 displays a fair translucency with traces of stoniness.

Specimen B-III-4 is a high grade porcelain with maximum translucency and a self-glazed surface.

Specimen B-III-5 shows signs of overmaturity. It has an opaque glassy appearance on the surface which destroys translucency.

Conclusions on Appearance of Series B.

Series B-I seems to indicate that we may expect good porcelain with .8 to 1.0 Al_2O_3, the RO and SiO_2 being as shown in this series.

Series B-II appears to show that we may not expect to obtain porcelain at this temperature unless we use at least one-half the RO as alkali. Above this amount we get good porcelains in every case, even where we use K_2O alone.

Series B-III confirms the conclusion in A-III that the variation of SiO_2 does not vary the appearance of the product so much as a variation of either of the other constituents. However, 3.2 SiO_2 seems insufficient, while 7.2 SiO_2 in undoubtedly an excess.

Series C. Tested Against Cone 12.

Specimen C-I-1 shows a maximum maturity. Very translucent and brilliantly self-glazed.

Specimen C-I-2 is a splendid porcelain, fine translucency and a good smooth surface.

Specimen C-I-3 shows a fair degree of translucency, with traces of stoniness.

Specimen C-I-4. Slightly translucent, marked stoniness.

Specimen C-I-5. Somewhat undermatured and little, if any, translucency.

Specimen C-II-1 is a good hard biscuit, but without any signs of translucency.

Specimen C-II-2 is a hard body, but still lacks any traces of translucency.

Specimen C-II-3 gives a good stony porcelain, with traces of translucency on exposed points.

Specimen C-II-4 is a fine translucent porcelain.

Specimen C-II-5 shows a very strongly translucent porcelain with an extremely glassy surface.

Conclusions on Appearance of Series C.

Series C-I shows us that undoubtedly a good porcelain at this temperature must contain, at least 0.8 Al_2O_3 and not over 1.0 Al_2O_3.

Series C-II indicates that even at this temperature we get no translucency from CaO. With all the RO as K_2O, we get a fine appearing body with maximum translucency.

We conclude from the previous tests and from Series C-I that Series C-III would give us a graded increase from stoniness to glassiness.

PREPARATION OF THE REGULAR TRIAL PIECES.

The preliminary testing having been completed, and having reassured me of the suitability of the series as projected to bring out the facts for which we were seeking, I then began the main work. The various bodies were prepared on sufficient scale, and were worked into the shapes heretofore decided upon and after drying each lot thoroughly, I fired them. It was impossible to obtain in the small kiln used, an absolutely uniform temperature over the entire kiln. However, I think I can say, that except in one case, all received an equal period of firing. All the pieces were imbedded in silica sand, except Series A-III from which the sand leaked away to some extent during the firing process. Series A had to be refired, as it was not fully matured at the first firing. Of course in such a line of work as I have pursued, the factor of error due to a variation of the process is very great, but I have made an effort to work all the bodies as nearly alike as possible and think that even with these factors of error present, we may find some valuable facts by a study of the results of the tests.

REMARKS ON THE RESULTS OF SERIES A.

ELECTRICAL RESISTANCE

As I only had 4½″x4½″ tile for this test, I could not expect to obtain above a test of 50,000 volts. For this reason I reduced the thickness of my tile at the center to about $\frac{3}{16}$ inch. The voltage for this test was obtained by means of a transformer provided for me by the Electrical Engineering Department of Ohio State University and operated by R. D. DeWolf, fellow in that department. Our power was obtained from the power circuit of O. S. U.

The test resulted as follows:

Series A-I— See Table

A-I-1 was melted out of shape and could not be tested. A-I-2 and A-I-3 stood the maximum voltage, arcing at 47,250 volts without puncturing. A-I-4 and A-I-5 both show a decreasing efficiency as insulators.

Of this group, I think A-I-3 seems the most desirable.

Series A-II— See Table

This series gives apparent confirmation to my opinion that a glassy porcelain has not the insulating strength of a semi-stony one.

A-II-1 shows a poor insulating power, due to imperfect vitrification.

A-II-2 seems improved in vitrification and shows a higher resistance.

A-II-3, which proved the best in the tensile test, again seems preferable, standing the maximum voltage applied.

A-II-4 stands the same voltage without puncturing, as did A-II-3, but its inferiority as shown in the tensile test makes it less desirable than the preceding specimen.

A-II-5 failed to stand up under the voltage applied and punctured at a maximum of 36,900 volts.

This, with its indicated weakness in tensile strength, would lead us to believe that we must look elsewhere than to pure feldspar porcelains for the highest insulating materials.

Series A-III— See Table

This series shows an increasing electrical resistence with an increasing proportion of SiO_2.

A-III-1 could not be worked in a dry press process due to the high clay contents. All the tiles cracked in burning, hence no electrical test was obtained.

A-III-2 punctured at 13,050 and 10,250 volts, respectively.

A-III-3 was only tested in $\frac{1}{2}$ inch thickness, as all the $\frac{3}{16}$ inch specimens were imperfect. At $\frac{1}{2}$ inch thickness, this specimen stood 39,400 volts without puncturing, the current arcing around the tile at this voltage.

A-III-4 at $\frac{3}{16}$ inch thickness stood the maximum voltage without puncturing and arced at 49,500 volts. A $\frac{3}{32}$ inch tile punctured at 38,250 volts.

A-III-5 at $\frac{3}{16}$ inch thick could not be punctured but arced around at 49,500 volts. However, the specimens all show over-maturity, which makes this composition an undesirable one.

I should consider A-III-4 as the best of this series.

ABRASION TEST.

The abrasion test was made by filling a large ball mill with two hundred pounds of flint pebbles and enough water to cover them completely. The brickettes were then weighed and placed in the mill, which was then closed and started. Two separate sets of tests were made upon each type of porcelain. One set was subjected to a test of 1000 revolutions and the other was subjected to a 2000 revolution test. The results are as follows:

Series A-I—See Table

A-I-1 seems to have either been softened and weakened by over-maturity, or to be naturally of a weak, fragile composition, due to lack of Al_2O_3 in its composition. The specimens of this type both wore badly, although they did not chip.

A-I-2 seems to have stood the test remarkably in one case, and broken down badly in the other case.

A-I-3 stood the 1000 revolution test and showed no signs of wear. It wore badly in the 2000 revolution test, however.

A-I-4 stood the 1000 revolution test well, but lost 2.03 per cent. on the 2000 revolution test.

A-I-5 lost 1.02 per cent. in the 1000 revolution test, indicating a uniform density and maturity throughout.

From the evidence at hand, A-I-4 is undoubtedly the choice of this series.

Series A-II—See Table

A-II-1, 2 and 3 can not be very satisfactorily compared from the data obtained, since one of each type was broken in the test and lost heavily from chipping.

A-II-4 and 5, both stood the tests without breaking in either case, but both lost considerably by wear.

Of this, Series A-II-4 seems the most desirable.

Series A-III — See Table

A-III-1 wore badly in both cases.

A-III-2 and 3 stood perfectly in the 1000 revolution test, but both broke in the 2000 revolution test.

A-III-5 loses nothing in either test. Hence, we must accept A-III-5 as the best as indicated from this test.

ABSORPTION TEST.

We only find three specimens of this series that are not completely vitrified. These are, A-I-5 and A-III-1 and 2. I cannot explain the cause of A-III-2 being soft. I think some error has been made in compounding this specimen, since A-III-2 seems at fault whenever tested, while A-I-2 and A-II-1, which are of the same composition, show no lack of vitrification.

TENSILE STRENGTH.

This test was made on a standard machine, using pasteboard around the ends of the brickettes to act as cushions and prevent cracking from direct contact with the jaws of the machine which were plain and not fitted with rolls as are the jaws of machines now made for testing cement brickettes. The brickettes when made had a central cross section of one square inch. This was reduced by shrinkage in drying and firing so that it was necessary to calculate the tensile strength per square inch in each case. The fractures resulting from this test proved very interesting and I believe very instructive. They are as follows:

Series A-I — See Tables

A-I-1 shows a glassy fracture, somewhat bloated and very open.

A-I-2 shows a very glassy fracture, but not so badly bloated as A-I-1.

A-I-3 has a fairly dense semi-glassy plane of fracture with little or no signs of bloating.

A-I-4 shows a dense porcelain fracture, somewhat stony in appearance.

A-I-5 has a dull grey fracture plane which shows traces of immaturity and porosity. A-I-5*a* showed a weak center which was yellow and apparently under-matured.

Of Series A-I, the strongest is either A-I-3 or A-I-4. A-I-3 shows considerable strength, but the bloating indicated over-maturity. A-I-5 shows weakness from immaturity, as might be expected.

Series A-II— See Tables

A-II-1 being the same as A-I-4 in composition, has much the same general appearance.

A-II-2 shows a slight increase in glossiness and a smoother fracture.

A-II-3 has a glossy fracture but is very dense. A-II-3b has large interior flaw which weakens it.

A-II-4 has a very glossy fracture which discloses minute cavities as evidence that bloating has begun.

A-II-5 displays a very badly bloated fracture full of large cavities.

Of the A-II series the test shows A-II-3 to be the best. This specimen has a composition of

$$\left.\begin{matrix}5\ K_2O\\5\ CaO\end{matrix}\right\} 1.Al_2O_3 \left\{ 4.2\ SiO_2 \right.$$

which seems to indicate that where calcium is much in excess, we do not get the degree of density unless it be just on the verge of the fusing period. Without density we cannot have strength. At the same time the test seems to condemn A-I-5 as being brittle from excess of K_2O which caused glassiness.

Series A-III— See Table

A-III-1 shows an under-matured creamy fracture with evidence of considerable porosity. A-III-1a has a flaw in the line of fracture, hence its weakness.

A-III-2 shows a somewhat denser stonier fracture and but little sign of glassiness. A-III-2a has a flaw along its plane of fracture.

A-III-3 does not show a very much denser structure than does A-III-2. I can not explain this.

A-III-4 shows a glossy surface, perfect vitrification and a close dense structure.

A-III-5 is completely vitrified but is glassy and shows traces of bloating.

Of this group I think A-III-4 is the best. This series tends to confirm the indication of series A-1 that increased SiO_2 brings density, since the density appears to steadily increase up to A-III-5, but this later shows signs of bloating which means that its limit of endurance is nearly reached.

SHRINKAGE TEST.

A study of the results of this test indicates that the specimen having the greatest shrinkage stands the most severe test. This is not always the most highly vitrified, but oftener the highest in clay substance.

In the discussion of this series, I would say that I think much more satisfactory results would have been obtained, had

$$\left.\begin{matrix}.5\ K_2O \\ .5\ CaO\end{matrix}\right\} \text{ been used instead of } \left\{\begin{matrix}.3\ K_2O. \\ .7\ CaO.\end{matrix}\right.$$

as a standard type.

The choice of this series lies between A-I-3 and 4, A-II-4 and A-III-3 and 4.

REMARKS ON THE RESULTS OF SERIES B.

We will now take up the results of Series B tests, which were made in the same manner as were those of Series A.

ELECTRICAL RESISTANCE

Series B-I — See Table

B-I-1 and 2 are both excellent insulators, standing 47,850 volts and arcing around. Neither were punctured.

B-I-3, 4 and 5 all broke at comparatively low voltages, indicating either immaturity or lack of insulating efficiency.

Of this series, I think B-I-2 is decidedly the best, as B-I-1 has too narrow a limit of fusibility after maturity is reached.

Series B-II — See Table

B-II-1 showed a decided weakness, due to lack of density. The flux here was CaO alone.

B-II-2 shows some improvement from the addition of a small amount of K_2O.

B-II-3 and 4 appear no better than the preceding so far as efficiency is concerned.

B-II-5 shows a slight improvement.

I think this entire series is too high in Al_2O_3 for this temperature, at least when made by the dry press process.

Series B-III— See Table

B-III-1 could not be tested, as every specimen cracked in burning, owing to an excess of clay.

B-III-2 shows a moderate degree of development as an insulator.

B-III-3 shows that a maximum of 49,500 volts is insufficient to puncture three-sixteenths inch.

B-III-4 and 5 also stand 49,500 volts, and then arc around without puncturing.

Of this series, the last three B-III-3, 4 and 5, all show greatly increased insulating power over the other numbers of the series. Of these, B-III-3 or 4 are both very superior porcelains, B-III-5 showing a slight over-maturity.

ABRASION TEST.

Series B-I— See Table

B-I-1 shows a nearly equal loss in both the 1000 and the 2000 revolution test.

B-I-2 shows an equally good body, standing both tests without chipping.

B-I-3 is somewhat more severely attacked, but even in the 2000 revolution test does not lose two per cent.

B-I-4 breaks into pieces in the 1000 revolution test, but stands the 2000 test without breaking. (The first case must have been a defective brickette.)

B-I-5 breaks both in the 1000 and 2000 revolution test.

Of this series I think B-I-2 and 3 are both good bodies.

Series B-II— See Table

B-II-1 wears very badly owing to its high CaO content and low degree of vitrification.

B-II-2 shows a decided improvement over the B-II-1 specimen.

B-II-3 loses nothing in the 1000 revolution test.

B-II-4 shows its increasing glassiness, due to its increasing K_2O content. It breaks in the 2000 revolution test and loses 10 per cent.

B-II-5 loses 10 per cent. in the 1000 revolution test and over 12 per cent. in the 2000 revolution test.

I think we are safe in selecting B-II-3 as the choice of this series.

Series B-III— See Table

B-III-1 loses about the average one per cent. in the 1000 revolution test and two per cent. in the 2000 revolution test.

B-III-2 broke in the 1000 test and lost 4.4 per cent. In the 2000 test it loses only 2.27 per cent.

B-III-3 broke in the 2000 revolution test, but stood the best test of any in the 1000 revolution test.

B-III-4 lost three per cent. and B-III-5 lost 3.45 per cent. by actual abrasion in the 2000 revolution test.

I think we may safely select B-III-3 as the best of this series.

ABSORPTION TEST.

The absorption test on series B shows only one specimen to be at all porous, viz.: B-II-1, in which CaO alone was used as a flux.

TENSILE TEST.

Series B-I— See Table

B-I-1 shows a porous, glassy fracture.

B-I-2 shows a much denser, but still a glassy fracture.

B-I-3 shows some signs of stoniness with a dense dull fracture.

B-I-4 shows a decidedly stony fracture, with a flinty appearing surface.

B-I-5 displays increased stoniness.

The tensile tests favor specimen B-I-4 very much, and since it stands 2449 pounds per square inch, in one specimen having an internal flaw, I think we may say that from this test we choose B-I-4 as the best.

Series B-II — See Table

In B-II series we see again, as in series A-II, the gradation caused by replacement of CaO by K_2O as a flux.

B-II-1 shows only a dense biscuit-like body with slight porosity.

B-II-2 has lost its porosity, but still lacks any trace of translucency and displays a purely clayey fracture.

B-II-3 give a splendid stony porcelain, with a dense smooth plane of fracture.

B-II-4 shows a glassier fracture plane and an appearance of brittleness.

B-II-5 has a brilliant fracture surface and indicates that it is decidedly brittle.

In this series the test shows very clearly that when more than 50 per cent. of the RO is K_2O, the body begins to deteriorate from brittleness, while with over 50 per cent. of the RO in the form of CaO, we note immaturity or lack of vitrification.

Series B-III — See Table

Series B-III shows an increasing strength with an increasing silica content.

B-III-1 shows a dull, stony plane of fracture.

B-III-2 shows an improvement in the appearance of the fracture over that noted in the preceding.

B-III-3 shows a very fair porcelain-like break with slight glassiness.

B-III-4 shows the same break as noted in fine high grade porcelains, but somewhat less translucency is apparent.

B-III-5 shows some signs of open structure due to overmaturity.

Of this, Series B-III-4 seems the most promising, with B-III-3 a close second.

SHRINKAGE TEST.

The shrinkage test on series B seemed to show little that we did not already know. The specimens high in K_2O maintain their size uniform with the rest of the series. Where two specimens of the same composition are unequally

matured, the specimen showing the greatest shrinkage invariably stands the severest test.

I think we may safely select B-I-2 from the B-I series as showing the best average in all tests. In B-II series, we find B-II-3 leads the others. In B-III series, specimen B-III-3 is the favorite.

REMARKS ON THE RESULTS OF SERIES C.

ELECTRICAL RESISTANCE.

Note that in series C the plates were only ⅛ inch in thickness, instead of 3-16 inch as in previous tests. A test is also recorded at ¼ inch thick.

C-I-1 stands the maximum, 34,000 volts at ⅛ inch thickness, and is not punctured at 47,500 at ¼ inch thick.

C-I-2 and 3 show a decreasing efficiency as insulators. C-I-4 is notably better than the two preceding in this respect, perhaps owing to its highly developed stony structure. The choice in this series is, however, C-I-1 or 2.

Series C-II shows an increasing electrical resistance with an increasing K_2O contents, but every specimen tested punctured, the best being the one of pure K_2O flux. This is contrary to the evident influences of K_2O alone as a flux according to the observations at lower temperatures. We must concede C-II-4 and 5 as the best of this series from the insulating efficiency evinced in this test.

ABRASION TEST.

Series C-I shows a magnificent record in this test. Both the 1000 and the 2000 revolution tests failed to in any way affect any of this series, and the blocks tested showed no evidence of having undergone any abrasive action whatever. I take it that this is a very strong argument in favor of high fire porcelain.

C-II-1 with CaO alone as a flux loses 8 to 12 per cent. by pure abrasion, showing that it lacks density and strength.

C-II-2 loses only 1.63 per cent. in the worst specimen, showing a marked improvement.

C-II-3 and 4 lose nothing in either case.

C-II-5 with K_2O alone as a flux loses 3.33 per cent. and 2.34 per cent. by chipping, which seems a characteristic of pure potash porcelain.

Of C-II series we may safely say that favorite is either C-II-3 or 4.

ABSORPTION TEST.

The test showed the entire series to be completely vitrified.

On the series C-II tests, specimen C-II-1 and 2 showed lack of perfect vitrification, the other members all proving perfectly vitrified.

TENSILE TEST.

Series C-I— See Table

C-I-1 shows a glassy fracture with a slight trace of over-maturity. That it is at its best is evinced by one specimen standing 2,100 pounds per square inch.

C-I-2 shows a fine close body with a good bright plane of fracture but no signs of over-maturity. One specimen stood 3071 pounds per square inch, the maximum strength displayed by any specimen in this work.

C-I-3 shows a good close structure and a tendency to stoniness.

C-I-4 is an extremely dense but a very stony porcelain.

C-I-5 shows an excess of clay in its composition as it has a dead and weak appearance to its fracture.

C-I-1 and 2 show the highest degree of tensile development of this series.

Series C-II— See Table

C-II-1 gives us only a good biscuit.

C-II-2 is a very hard biscuit, but lacking in vitrification and translucency.

C-II-3 has a close structure with good vitrification and dense stoniness.

C-II-4 is a good semi-stony porcelain with a splendid appearance of translucency.

C-II-5 is a fine well matured porcelain of a glassy nature.

The choice of the above as indicated by the tensile test would be C-II-4 or 5.

SHRINKAGE TEST.

The tests showed a slightly increasing shrinkage with an increase of Al_2O_3 from clay substance until C-I-3 is reached. Above this no increased shrinkage is apparent. In the C-II series, the increased K_2O seemed to cause increased shrinkage.

C-II-2 for some reason shrinks equally with C-II-4 and 5. My only explanation of this would be that the large amount of clay substance present in this specimen is enabled to act by the addition of the small amount of feldspar.

Why C-II-3, also, did not shrink proportionately I can not explain. I note, however, that in every case the first addition of K_2O seems to cause an increased shrinkage, not continuing to increase in the higher K_2O porcelains.

We may choose from Series C-I as favorites, either C-I-1 or 2. From Series C-II, I think C-II-4 is the best.

The data which have been discussed in the foregoing, will be found in tabular form in the following eight pages:

TESTS OF SERIES.

A—I

ELECTRICAL RESISTANCE TEST.

No.		Thickness	Puncturing Voltage	Remarks:
1	a	———	———	Melted out of shape and could not be tested.
	b	———	———	
2	a	$\frac{3}{16}$ inch.	Not punct'd	Arced around at 47,250 Volts.
	b	$\frac{3}{16}$ "	" "	" " at 47,250 "
3	a	$\frac{3}{16}$ "	" "	" " at 47,250 "
	b	—	———	
4	a	$\frac{3}{16}$ "	14,400	
	b	$\frac{3}{16}$ "	13,500	
5	a	$\frac{3}{16}$ "	11,475	
	b	$\frac{3}{16}$ "	10,575	

ABRASION TEST
With 200 Pounds Flint Pebbles in Wet Ball-Mill

No.		Before Test	After Test	Per Cent. Loss
1	a	51.0 grs.	49.0 grs.	3.92
	b	49.0 "	47.0 "	4.08
2	a	52.5 "	52.0 "	0 95
	b	63.0 "	58.5 "	7.14
3	a	48.0 "	47.0 "	2.08
	b	48.7 "	48.5 "	0.51
4	a	49.2 "	48.2 "	2.03
	b	47.5 "	47.5 "	———
5	a	48.0 "	47.0 "	2.08
	b	49.0 "	48.5 "	1.02

a= 2000 revolution test.
b= 1000 " "

ABSORPTION TEST.

No.		Before Soaking	After Soaking	Per Cent. Absorpt'n
1	a	51.0 grs.	51.0 grs.	———
	b	49.0 "	49.0 "	———
2	a	52.5 "	52.0 "	———
	b	63.0 "	63.0 "	———
3	a	48.0 "	48.0 "	———
	b	48.7 "	48.7 "	———
4	a	49.2 "	49.2 "	———
	b	47.5 "	47.5 "	———
5	a	45.5 "	48.0 "	5.50
	b	48.5 "	49.0 "	1.03

TENSILE TEST.

No.		Area of Cross Section.	Load Neces'ary to Break	Tensile Strength of 1 Sq. Inch
1	a	$\frac{12}{16}$ x $\frac{14}{16}$	912 lbs.	1390 lbs.
	b	— x —	——— "	——— "
2	a	$\frac{27}{32}$ x $\frac{14}{16}$	1777 "	2408 "
	b	$\frac{27}{32}$ x $\frac{29}{32}$	1653 "	2161 "
3	a	$\frac{14}{16}$ x $\frac{29}{32}$	1882 "	2373 "
	b	$\frac{14}{16}$ x $\frac{14}{16}$	1918 "	2505 "
4	a	$\frac{14}{16}$ x $\frac{27}{32}$	1766 "	2391 "
	b	$\frac{14}{16}$ x $\frac{13}{16}$	2038 "	2866 "
5	a	$\frac{14}{16}$ x $\frac{14}{16}$	904 "	1181 "
	b	$\frac{15}{16}$ x $\frac{13}{16}$	1566 "	2056 "

SHRINKAGE TEST.

No.		Area Green	Area Burned	Per Cent. Loss
1	a	1. Sq. In.	.656 sq.in	34.40
	b	— "	——— "	———
2	a	1. "	.738 "	26.20
	b	1. "	.764 "	23.54
3	a	1. "	.793 "	20.70
	b	1. "	.765 "	23.44
4	a	1. "	.738 "	26.17
	b	1. "	.711 "	28.90
5	a	1. "	.765 "	23.44
	b	1. "	.761 "	23.83

TESTS OF SERIES. (Continued)

A-II.

ELECTRICAL RESISTANCE TEST.

No.		Thickness	Puncturing Voltage	Remarks:
1	a	$\frac{3}{16}$ inch	10,700	
	b	— "	—	
2	a	$\frac{3}{16}$ "	23,625	
	b	$\frac{3}{16}$ "	36,000	
3	a	$\frac{3}{16}$ "	Not punct'd	Arced around at 47,250 Volts
	b	$\frac{3}{16}$ "	" "	" " " 47,250 "
4	a	$\frac{3}{16}$ "	" "	" " " 47,250 "
	b	$\frac{3}{16}$ "	" "	" " " 47,250 "
5	a	$\frac{3}{16}$ "	36,900	
	b	$\frac{3}{16}$ "	27,450	

ABRASION TEST
With 200 Pounds Pebbles in Wet Ball-Mill

No.		Before Test	After Test	Per Cent. Loss
1	a	40.0 grs.	38.0 grs.	5.00
	b	45.0 "	43.0 "	4.44
2	a	45.0 "	43.0 "	4.44
	b	45.2 "	44.5 "	1.67
3	a	49.5 "	46.5 "	6.05
	b	49.0 "	48.5 "	1.02
4	a	53.5 "	53.0 "	0.94
	b	45.5 "	45.0 "	1.10
5	a	55.0 "	54.0 "	1.81
	b	50.5 "	50.0 "	0.99

a = 2000 revolution test.
b = 1000 " "

ABSORPTION TEST.

No.		Before Soaking	After Soaking	Per Cent. Absorpt'n
1	a	40.0 grs.	40.0 grs.	——
	b	45.0 "	45.0 "	——
2	a	45.0 "	45.0 "	——
	b	45.2 "	45 2 "	——
3	a	49.5 "	49.5 "	——
	b	49.0 "	49.0 "	——
4	a	53.5 "	53.5 "	——
	b	45.5 "	45.5 "	——
5	a	55.0 "	55.0 "	——
	b	50.5 "	50.5 "	——

TENSILE TEST.

No.		Area of Cross Section	Load Neces'ary to Break	Tensile Strength of 1 Sq. Inch
1	a	$\frac{29}{32}$ x $\frac{14}{16}$	887 lbs.	1118 lbs.
	b	$\frac{14}{16}$ x $\frac{14}{16}$	1416 "	1850 "
2	a	$\frac{25}{32}$ x $\frac{14}{16}$	1382 "	2023 "
	b	$\frac{27}{32}$ x $\frac{13}{16}$	1434 "	2092 "
3	a	$\frac{27}{32}$ x $\frac{13}{16}$	1743 "	2543 "
	b	$\frac{25}{32}$ x $\frac{14}{16}$	*1439 "	2099 " *
4	a	$\frac{25}{32}$ x $\frac{29}{32}$	1190 "	1681 "
	b	$\frac{25}{32}$ x $\frac{29}{32}$	1175 "	1660 "
5	a	$\frac{13}{16}$ x $\frac{29}{32}$	1358 "	1845 "
	b	$\frac{13}{16}$ x $\frac{15}{16}$	*525 "	690 " *

* Indicates a defective brickette.

SHRINKAGE TEST.

No.		Area Green	Area Burned	Per Cent. Loss
1	a	1. Sq. In.	.793 sq.in	20.70
	b	1. "	.765 "	23.50
2	a	1. "	.683 "	31.65
	b	1. "	.685 "	31.45
3	a	1. "	.685 "	31.45
	b	1. "	.685 "	31.45
4	a	1. "	.708 "	29.20
	b	1. "	.708 "	29.20
5	a	1. "	.736 "	26.40
	b	1. "	.761 "	23.83

TESTS OF SERIES. (Continued.)

A-III

ELECTRICAL RESISTANCE TEST.

No.		Thickness	Puncturing Voltage	Remarks:
1	a	$\frac{3}{16}$ inch.	————	Broke in burning.
	b	———	————	
2	a	$\frac{3}{16}$ "	13,050	
	b	$\frac{3}{16}$ "	10,250	
3	a	$\frac{3}{16}$ "	19,200	
	b	$\frac{3}{16}$ "	20,750	
4	a	$\frac{3}{16}$ "	38,250	
	b	$\frac{3}{16}$ "	Not punct'd	Arced around at 49,500 Volts.
5	a	$\frac{3}{16}$ "	" "	" " at 49,500 "
	b	$\frac{3}{16}$ "	————	Defective.

ABRASION TEST
With 200 Pounds Flint Pebbles in Wet Ball-Mill

No.		Before Test	After Test	Per Cent. Loss
1	a	38.5 grs.	37.2 grs.	3.25
	b	50.2 "	49.0 "	2.49
2	a	42.0 "	40.0 "	4.76
	b	45.2 "	45.2 "	——
3	a	45.5 "	43.5 "	4.40
	b	42.0 "	42.0 "	——
4	a	53.0 "	52.2 "	1.41
	b	47.0 "	47.0 "	——
5	a	45.5 "	45.5 "	——
	b	50.0 "	50.0 "	——

a=2000 revolution test.
b=1000 " "

ABSORPTION TEST.

No.		Before Soaking	After Soaking	Per Cent. Absorpt'n
1	a	33.5 grs.	38.5 grs.	13.16
	b	44.5 "	50.2 "	12.92
2	a	40.5 "	42.0 "	3.70
	b	43.0 "	45.2 "	5.23
3	a	45.5 "	45.5 "	——
	b	42.0 "	42.0 "	——
4	a	53.0 "	53.0 "	——
	b	47.0 "	47.0 "	——
5	a	45.5 "	45.5 "	——
	b	50.0 "	50.0 "	——

TENSILE TEST.

No.		Area of Cross Section.	Load Neces'ary to Break	Tensile Strength of 1 Sq. Inch
1	a	$\frac{29}{32}$ x $\frac{27}{32}$	380 lbs.	498 lbs.*
	b	$\frac{29}{32}$ x $\frac{29}{32}$	1035 "	1260 "
2	a	$\frac{27}{32}$ x $\frac{25}{32}$	698 "	1059 " *
	b	$\frac{27}{32}$ x $\frac{25}{32}$	1200 "	1820 "
3	a	$\frac{29}{32}$ x $\frac{13}{16}$	1288 "	1749 "
	b	$\frac{28}{32}$ x $\frac{27}{32}$	1215 "	1624 "
4	a	$\frac{27}{32}$ x $\frac{25}{32}$	1403 "	2130 "
	b	$\frac{13}{16}$ x $\frac{13}{16}$	1724 "	2612 "
5	a	$\frac{25}{32}$ x $\frac{14}{16}$	1985 "	2902 "
	b	$\frac{25}{32}$ x $\frac{14}{16}$	1567 "	2292 "

*Indicates a defective brickette.

SHRINKAGE TEST.

No.		Area Green	Area Burned	Per Cent. Loss
1	a	1. Sq. In.	.764 sq.in	23.54
	b	1. "	.821 "	17.88
2	a	1. "	.659 "	34.08
	b	1. "	.659 "	34.08
3	a	1. "	.736 "	26.37
	b	I. "	.748 "	25.20
4	a	1. "	.659 "	34.08
	b	1. "	.660 "	33.99
5	a	1. "	.683 "	31.64
	b	1. "	.683 "	31.64

TESTS OF SERIES. (Continued)
B-I.

ELECTRICAL RESISTANCE TEST.

No.		Thickness	Puncturing Voltage	Remarks:
1	a	$\frac{3}{16}$ inch	Not punct'd	Arced around at 47,850 Volts.
	b	$\frac{3}{16}$ "	" "	" " " 47,850 "
2	a	$\frac{3}{16}$ "	" "	" " " 47,850 "
	b	$\frac{3}{16}$ "	" "	" " " 47,850 "
3	a	$\frac{3}{16}$ "	17,100	
	b	$\frac{3}{16}$ "	16,200	
4	a	$\frac{3}{16}$ "	18,000	
	b	— "		
5	a	$\frac{3}{16}$ "	26,550	
	b	$\frac{3}{16}$ "	27,450	

ABRASION TEST
With 200 Pounds Flint Pebbles in Wet Ball-Mill

No.		Before Test	After Test	Per Cent. Loss
1	a	45.5 grs.	45.0 grs.	1.10
	b	42.5 "	42.0 "	1.17
2	a	41.0 "	40.0 "	1.22
	b	50.5 "	50.0 "	0.99
3	a	42.7 "	42.0 "	1.75
	b	41.5 "	41.0 "	1.20
4	a	43.7 "	43.0 "	1.71
	b	41.5 "	40.5 "	2.16
5	a	42.7 "	40.5 "	5.26
	b	38.5 "	38.2 "	0.64

a=2000 revolution test.
b=1000 " "

ABSORPTION TEST.

No.		Before Soaking	After Soaking	Per Cent. Absorpt'n
1	a	47.7 grs.	47.7 grs.	——
	b	42.5 "	42.5 "	——
2	a	51.0 "	51.0 "	——
	b	50.5 "	50.5 "	——
3	a	44.0 "	44.0 "	——
	b	41.5 "	41.5 "	——
4	a	45.7 "	45.7 "	——
	b	41.5 "	41.5 "	——
5	a	46.0 "	46.0 "	——
	b	38.5 "	38.5 "	——

TENSILE TEST.

No.		Area of Cross Section	Load Neces'ary to Break	Tensile Strength of 1 Sq. Inch
1	a	$\frac{29}{32}$ x $\frac{12}{16}$	1455 lbs.	1977 lbs.
	b	$\frac{25}{32}$ x $\frac{14}{16}$	1339 "	1959 "
2	a	$\frac{29}{32}$ x $\frac{13}{16}$	990 "	1345 "
	b	$\frac{14}{16}$ x $\frac{13}{16}$	1514 "	2129 "
3	a	$\frac{25}{32}$ x $\frac{14}{16}$	1293 "	1891 "
	b	$\frac{29}{32}$ x $\frac{13}{16}$	1104 "	1500 "
4	a	$\frac{12}{16}$ x $\frac{27}{32}$	1550 "	2449 "
	b	$\frac{12}{16}$ x $\frac{27}{32}$	1457 "	2302 "
5	a	$\frac{27}{32}$ x $\frac{25}{32}$	637 " *	944 " *
	b	$\frac{27}{32}$ x $\frac{25}{32}$	1171 "	1850 "

* Indicates a defective brickette.

SHRINKAGE TEST.

No.		Area Green	Area Burned	Per Cent. Loss
1	a	1. Sq. In.	.736 sq.in	26.40
	b	1. "	.683 "	31.64
2	a	1. "	.736 "	26.40
	b	1. "	.711 "	28.90
3	a	1. "	.683 "	31.64
	b	1. "	.736 "	26.37
4	a	1. "	.632 "	36.72
	b	1. "	.632 "	36.72
5	a	1. "	.675 "	32.50
	b	1. "	.632 "	36.72

TESTS OF SERIES. (Continued)

B-II.

ELECTRICAL RESISTANCE TEST.

No.		Thickness	Puncturing Voltage	Remarks:
1	a	$\frac{3}{16}$ inch	16,650	
	b	$\frac{3}{16}$ "	18,450	
2	a	$\frac{3}{16}$ "	15,975	
	b	$\frac{3}{16}$ "	18,900	
3	a	$\frac{3}{16}$ "	15,300	
	b	$\frac{3}{16}$ "	16,650	
4	a	$\frac{3}{16}$ "	17,100	
	b	— "	———	Punctured at 34,500 Volts, $\frac{5}{8}$ in. thick.
5	a	$\frac{3}{16}$ "	19,125	
	b	— "	———	Punctured at 47,250 Volts, $\frac{5}{8}$ in. thick.

ABRASION TEST
With 200 Pounds Flint Pebbles in Wet Ball-Mill

No.		Before Test	After Test	Per Cent. Loss
1	a	43.7 grs.	40.0 grs.	8.57
	b	45.5 "	44.5 "	2.20
2	a	45.0 "	44.5 "	1.10
	b	45.7 "	45.5 "	0.55
3	a	42.0 "	41.0 "	2.38
	b	41.5 "	41.5 "	——
4	a	40.5 "	36.5 "	10.00
	b	44.5 "	43.5 "	2.24
5	a	46 0 "	41.0 "	10.87
	b	49.5 "	43.5 "	12.12

a= 2000 revolution test.
b= 1000 " "

ABSORPTION TEST.

No.		Before Soaking	After Soaking	Per Cent. Absorpt'n
1	a	42.0 grs.	47.2 grs.	12.5
	b	40.5 "	45.5 "	11.1
2	a	39.0 "	39.0 "	——
	b	45.7 "	45.7 "	——
3	a	52.2 "	52.2 "	——
	b	41.5 "	47.5 "	——
4	a	55.5 "	55.5 "	——
	b	44.5 "	44.5 "	——
5	a	50.0 "	50.0 "	——
	b	49.5 "	49.5 "	——

TENSILE TEST.

No.		Area of Cross Section	Load Necesa'ry to Break	Tensile Strength of 1 Sq. Inch
1	a	$\frac{15}{16}$ x $\frac{14}{16}$	623 lbs.	759 lbs.
	b	$\frac{29}{32}$ x $\frac{15}{16}$	690 "	812 "
2	a	$\frac{27}{32}$ x $\frac{13}{16}$	1352 "	1971 "
	b	$\frac{27}{32}$ x $\frac{13}{16}$	1345 "	1962 "
3	a	$\frac{14}{16}$ x $\frac{13}{16}$	1425 "	2004 "
	b	$\frac{29}{32}$ x $\frac{13}{16}$	1980 "	2692 "
4	a	$\frac{14}{16}$ x $\frac{13}{16}$	1565 "	2201 "
	b	$\frac{14}{16}$ x $\frac{13}{16}$	1421 "	1925 "
5	a	$\frac{14}{16}$ x $\frac{13}{16}$	1160 "	1631 "
	b	$\frac{14}{16}$ x $\frac{13}{16}$	1173 "	1590 "

SHRINKAGE TEST.

No.		Area Green	Area Burned	Per Cent. Loss
1	a	1. Sq. In.	.820 sq.in	18.0
	b	1. "	.850 "	15.0
2	a	1. "	.685 "	31.4
	b	1. "	.685 "	31.4
3	a	1. "	.711 "	28.9
	b	1. "	.738 "	26.4
4	a	1. "	.711 "	28.9
	b	1. "	.738 "	26.4
5	a	1. "	.711 "	28.9
	b	1. "	.738 "	26.4

TESTS OF SERIES. (Continued.)

B-III

ELECTRICAL RESISTANCE TEST.

No.		Thickness	Puncturing Voltage	Remarks:
1	a	———	———	Burst in firing.
	b	———	———	
2	a	$\frac{3}{16}$ inch.	31.050	
	b	$\frac{1}{8}$ "	25,500	
3	a	$\frac{3}{16}$ "	Not punct'd	Arced around at 49,500 Volts.
	b	$\frac{3}{16}$ "	" "	" " at 49,500 "
4	a	$\frac{3}{16}$ "	" "	" " at 49,500 "
	b	— "	———	
5	a	$\frac{3}{16}$ "	Not punct'd	Arced around at 49,500 Volts.
	b	$\frac{3}{16}$ "	" "	" " at 49,500 "

ABRASION TEST
With 200 Pounds Flint Pebbles in Wet Ball-Mill

No.		Before Test	After Test	Per Cent. Loss
1	a	39.5 grs.	38.5 grs.	2.53
	b	45.5 "	45.0 "	1.10
2	a	44.0 "	43.0 "	2.27
	b	45.0 "	43.0 "	4.44
3	a	47.0 "	41.5 "	11.70
	b	57.5 "	57.0 "	0.87
4	a	49.5 "	48.0 "	3.03
	b	56.5 "	55.7 "	1.32
5	a	58.0 "	56.0 "	3.45
	b	51.5 "	51.0 "	0.97

a=2000 revolution test.
b=1000 " "

ABSORPTION TEST

No.		Before Soaking	After Soaking	Per Cent. Absorpt'n
1	a	42.0 grs.	42.0 grs.	——
	b	45.5 "	45.5 "	——
2	a	50.0 "	50.0 "	——
	b	45.0 "	45.0 "	——
3	a	50.7 "	50.7 "	——
	b	57.5 "	57.5 "	——
4	a	58.7 "	58.7 "	——
	b	56.5 "	56.5 "	——
5	a	56.0 "	56.0 "	——
	b	51.5 "	51.5 "	——

TENSILE TEST.

No.		Area of Cross Section	Load Neces'ary to break	Tensile Strength of 1 Sq. Inch
1	a	$\frac{14}{16}$ x $\frac{27}{32}$	825 lbs.	1118 lbs.*
	b	$\frac{14}{16}$ x $\frac{27}{32}$	2070 "	2805 "
2	a	$\frac{14}{16}$ x $\frac{13}{16}$	1220 "	1697 "
	b	$\frac{14}{16}$ x $\frac{13}{16}$	1511 "	2101 "
3	a	$\frac{14}{16}$ x $\frac{12}{16}$	1465 "	2233 "
	b	$\frac{14}{16}$ x $\frac{12}{16}$	1474 "	2247 "
4	a	$\frac{14}{16}$ x $\frac{25}{32}$	1755 "	2569 "
	b	$\frac{14}{16}$ x $\frac{13}{16}$	1715 "	2385 "
5	a	$\frac{27}{32}$ x $\frac{13}{16}$	1504 "	2194 "
	b	$\frac{14}{16}$ x $\frac{13}{16}$	1298 "	1805 "

*Indicates a defective brickette.

SHRINKAGE TEST.

No.		Area Green	Area Burned	Per Cent. Loss
1	a	1.0 Sq.In	.738sq.in	26.2
	b	1.0 "	.738 "	26.2
2	a	1.0 "	.719 "	28.1
	b	1.0 "	.719 "	28.1
3	a	1.0 "	.656 "	34.4
	b	1.0 "	.656 "	34.4
4	a	1.0 "	.683 "	31.6
	b	1.0 "	.719 "	28.1
5	a	1.0 "	.685 "	31.4
	b	1.0 "	.719 "	28.1

TESTS OF SERIES. (Continued.)

C—I

ELECTRICAL RESISTANCE TEST.

No.		Thickness	Puncturing Voltage	Remarks:
1	a	1/8 inch.	34,000	
	b	1/4 "		Arced around at 47,500 volts.
2	a	1/8 "	25,750	
	b	1/4 "	47,000	
3	a	1/8 "	17,250	
	b	1/4 "	18,550	
4	a	1/8 "	22,000	
	b	1/4 "	21,000	Defective.
5	a	1/8 "		
	b	1/4 "	14,900	

ABRASION TEST
With 200 Pounds Flint Pebbles in Wet Ball-Mill

No.		Before Test	After Test	Per Cent. Loss
1	a	36.0 grs.	36.0 grs.	.00
	b	39.5 "	39.5 "	.00
2	a	36.5 "	36.5 "	.00
	b	40.0 "	40.0 "	.00
3	a	41.5 "	41.5 "	.00
	b	41.5 "	41.5 "	.00
4	a	38.5 "	38.5 "	.00
	b	37.7 "	37.7 "	.00
5	a	33.7 "	33.7 "	.00
	b	33.7 "	33.7 "	.00

a = 2000 revolution test.
b = 1000 " "

ABSORPTION TEST.

No.		Before Soaking	After Soaking	Per Cent. Absorpt'n
1	a	36.0 grs.	36.0 grs.	.00
	b	39.5 "	39.5 "	.00
2	a	36.5 "	30.5 "	.00
	b	40.0 "	40.0 "	.00
3	a	41.5 "	41.5 "	.00
	b	41.5 "	41.5 "	.00
4	a	38.5 "	38.5 "	.00
	b	37.7 "	37.7 "	.00
5	a	33.7 "	33.7 "	.00
	b	33.7 "	33.7 "	.00

TENSILE TEST

No.		Area of Cross Section	Load Neces'ary to Break	Tensile Strength of 1 Sq. Inch
1	a	27/32 x 27/32	2094 lbs.	2942 lbs.
	b	27/32 x 27/32	1494 "	2099 "
2	a	13/16 x 27/32	1361 "	1985 "
	b	13/16 x 27/32	2105 "	3071 "
3	a	25/32 x 25/32	1585 "	2404 "
	b	25/32 x 25/32	1330 "	2018 " *
4	a	13/16 x 13/16	1686 "	2555 "
	b	13/16 x 13/16	1543 "	2308 "
5	a	25/32 x 13/16	1373 "	2163 "
	b	13/16 x 13/16	1729 "	2619 "

*Indicates a defective brickette.

SHRINKAGE TEST

No.		Area Green	Area Burned	Per Cent. Loss
1	a	1. Sq. In.	.7118sqin	28.82
	b	1. "	.7118 "	28.82
2	a	1. "	.6855 "	31.45
	b	1. "	.6855 "	31.45
3	a	1. "	.6592 "	34.08
	b	1. "	.6592 "	34.08
4	a	1. "	.6601 "	33.99
	b	1. "	.6601 "	33.99
5	a	1. "	.6348 "	36.52
	b	1. "	.6601 "	33.99

TESTS OF SERIES. (Continued)

C-II.

ELECTRICAL RESISTANCE TEST.

No.		Thickness	Puncturing Voltage	Remarks:
1	a	1/8 inch	———	
	b	1/4 "	13,500	
2	a	1/8 "	14,500	
	b	1/4 "	15,200	
3	a	1/8 "	14,000	
	b	1/4 "	14,300	
4	a	1/8 "	14,250	
	b	1/4 "	23,750	
5	a	1/8 "	18,750	
	b	1/4 "	36,000	

ABRASION TEST
With 200 Pounds Flint Pebbles in Wet Ball-Mill

No.		Before Test	After Test	Per Cent. Loss
1	a	30.0 grs.	30.2 grs.	8.33
	b	33.0 "	29.0 "	12.12
2	a	30.0 "	29.7 "	0.83
	b	30.7 "	30.2 "	1.63
3	a	33.0 "	33.0 "	0.00
	b	28.5 "	28.5 "	0.00
4	a	30.5 "	30.5 "	0.00
	b	30.5 "	30.5 "	0.00
5	a	32.0 "	31.2 "	2.34
	b	30.0 "	29.0 "	3.33

a = 2000 revolution test.
b = 1000 " "

ABSORPTION TEST.

No.		Before Soaking	After Soaking	Per Cent. Absorpt'n
1	a	29.0 grs.	33.0 grs.	13.8
	b	29.0 "	33.0 "	13.8
2	a	29.5 "	30.0 "	1.7
	b	30.0 "	30.7 "	2.5
3	a	33.0 "	33.0 "	——
	b	28.5 "	28.5 "	——
4	a	30.5 "	30.5 "	——
	b	30.5 "	30.5 "	——
5	a	32.0 "	32.0 "	——
	b	30.0 "	30.0 "	——

TENSILE TEST.

No.		Area of Cross Section	Load Neces'ary to Break	Tensile Strength of 1 Sq. Inch
1	a	7/8 x 7/8	843 lbs.	1101 lbs.
	b	27/32 x 29/32	876 "	1145 "
2	a	25/32 x 13/16	1018 "	1604 "
	b	25/32 x 13/16	1084 "	1706 "
3	a	13/16 x 13/16	410 "*	—— "*
	b	13/16 x 13/16	1157 "	1753 "
4	a	25/32 x 13/16	1140 "*	1796 "*
	b	25/32 x 13/16	1643 "	2585 "
5	a	25/32 x 13/16	705 "*	—— "*
	b	25/32 x 13/16	1492 "	2350 "

* Indicates a defective brickette.

SHRINKAGE TEST.

No.		Area Green	Area Burned	Per Cent. Loss
1	a	1. Sq. In.	.765 sq.in	23.44
	b	1. "	.764 "	23.56
2	a	1. "	.634 "	36.52
	b	1. "	.634 "	36.52
3	a	1. "	.660 "	33.99
	b	1. "	.660 "	33.99
4	a	1. "	.634 "	36.52
	b	1. "	.634 "	36.52
5	a	1. "	.634 "	36.52
	b	1. "	.634 "	36.52

GENERAL CONCLUSIONS ON THE WORK AS COMPLETED.

The object of this investigation was to prove, if possible, the proportions of the essential constituents which go to make up the best insulating porcelains. By the test, we have learned that porcelains of equally good appearance may possess greatly varying values when subjected to various tests. The essential properties of an electrical insulator are: That it possess, first of all, a high efficiency as a non-conductor. Second, that it stand, without snapping, any reasonable strain put upon it by the exigencies of wiring. Third, that it withstand the blows of missiles, even bullets, without breaking. The electrical, the tensile and the abrasion tests, respectively, were made to show these properties in the porcelains tested.

From a study of the electrical resistance tests we have found that every specimen standing a superior test has a high silica and moderately low alumina content. Unfortunately in each series showing the variation in proportions of CaO and K_2O, the content of Al_2O_3 was so high that no exceptionally good porcelains were obtained, even with high K_2O content. However, a study of tables A-II, B-II and C-II will show the reader that a marked improvement is apparent upon increasing the K_2O and decreasing the CaO, except at the extreme of the series where we see the K_2O used alone, and here the specimens show weakness due to brittleness. I infer from this study that had the K_2O been somewhat increased, and the CaO proportionately decreased in series I and III, these series would have proved much better.

From a study of the abrasion tests, it is very apparent that with K_2O alone as a flux, and even with a moderately high clay substance, we obtain a brittle and weak porcelain. When as low as 20 per cent of K_2O is replaced by CaO, we find the product changed to a tough but well vitrified body, although I believe that the translucency is reduced by any additions of CaO. To just what extent this is the case is not a matter of importance in this work. In the series showing the effect of Al_2O_3 content, I notice

no great difference in the ability of the specimens to resist abrasion. Much the same statement would apply to the series showing the results of varying of SiO_2. However, I note that the medium high SiO_2 specimens seem to chip worse than the extremely high SiO_2 specimens, while the low SiO_2 specimens show a lack of ability to resist abrasion.

A study of the test tables will show the reader that of the forty different porcelains tested, we find six to be more or less porous. It appears that the statements made in discussing the tensile tests hold here also, and that the same limits may be accepted. I also note that CaO when substituted for an equal equivalent of K_2O, does not at either cone 6, cone 9, or cone 12, produce an equal amount of vitrification.

My conclusions from a study of the tensile tests are that a moderately high SiO_2 and Al_2O_3 content will bring a good strong porcelain, but that not over 1. Al_2O_3 and 6.2 SiO_2 should be used. None of the specimens below .8 Al_2O_3 and 4.2 SiO_2 were safe, owing to their very narrow vitrification limits. The RO that proved most satisfactory in the tensile tests was between

$$\left\{\begin{matrix}40 \text{ per cent. } K_2O \\ 60 \text{ per cent. } CaO\end{matrix}\right. \text{ and } \left.\begin{matrix}80 \text{ per cent. } K_2O \\ 20 \text{ per cent. } CaO\end{matrix}\right\}$$

The shrinkage tests tend to show, I think, that there are three factors that may cause a variation: (1) The amount of clay substance introduced. (2) The variation in the kind of flux used. (3) The amount of silica present. Hence the shrinkage may be varied to suit almost any case.

In closing this paper, I think I may say that in my opinion an ideal porcelain for electrical purposes, may mature at any point between cone 6 or cone 12. It may contain from 50 per cent. to 80 per cent of its RO in the form of K_2O and the remainder as CaO. It may contain from .8 Al_2O_3 to 1.0 Al_2O_3 and from 4.2 SiO to 6.2 SiO_2. Expressing the same fact in formula form, we would have

$$\left.\begin{matrix}0.5 \text{ to } 0.8\ K_2O \\ 0.5 \text{ to } 0.2\ CaO\end{matrix}\right\} \ 0.8 \text{ to } 1.0\ Al_2O_3 \left\{ \ 4.2 \text{ to } 6.2\ SiO_2$$

as the practical range of composition.

Closer limits than these I do not feel able to lay down, as the choice would be largely a matter of fancy for more translucency or more stoniness to be decided by the party interested. However, I think I may safely say that any porcelain within the limits named above, would, all other things being equal, be as good as, if not superior to the average electrical insulator porcelain now on the market.

DISCUSSION.

The Chair: Mr. Watts is certainly to be congratulated upon the able manner in which he has handled this subject. It is the first composition which has ever appeared in this or any other country on porcelain in which the matter of composition and electrical resistance are brought into comparison. I know you are all thinking now how hard it is going to be to discuss such an enormous mass of facts as Mr. Watts has patiently accumulated and presented here today. It certainly deserves some discussion, and an expression from the society of the recognition of its merits. I think Professor Orton would probably be glad to start the discussion. He has probably given some thought to the subject before he came here.

Professor Orton: I cannot say anything about the paper except to express my admiration for the patience and fidelity with which Mr. Watts has carried out his task. It has involved three months' patient labor, and there were a good many occasions upon which he was obliged to sit up all night, in order to carry through a test; and I think I may fairly say that there are not so very many people in this society or outside of it, who would be willing, for the sake of scientific advancement, to devote three months of their time, without recompense, to an investigation of this sort. In my opinion, it marks an era in the life of this society, when a young man of training, opportunity and experience, is willing to present a subject upon which so little is known and upon which so high a commercial valuation is placed.

The transactions of the electrical societies of the world contain records of a great variety of tests on electrical resistance, and the subject has been very carefully studied by

them to find a material to help out in the handling of high tension currents. But so far as I am aware (Mr. Watts will correct me if the statement is not true), no one has before attempted to show the relation between the composition of porcelain, and its ability to resist high tension currents; and I consider it a great honor for the American Ceramic Society to be the medium of presentation to the world of the first authentic information of this character. As far as discussing the paper on its merits is concerned, I am entirely unable to do so.

It occurs to me to ask Mr. Watts to describe to the society the way an electric current acts on arcing around an obstruction or insulation. Can you show us just how that occurs?

Mr. Watts: (Makes illustration on blackboard). Those of you who have had experience with any kind of electrical work know that when a current reaches a certain tension, the tendency is to complete the circuit, no matter what the distance. Electrical engineers have determined the actual voltage necessary to jump a certain distance of air; and as I stated in my paper, about five inches of air space will be arced through, or crossed by the current at a voltage of 55,000; and in order to puncture the insulator, you must have an insulating material extending beyond that distance or make the insulation less perfect. That is the reason so many of my tiles could not be punctured. I hoped that I had made them so thin that the resistance of the porcelain would not be equal to the pressure of fifty thousand volts, but I was mistaken.

The modern high-voltage electrical insulator is made with two or three bonnets or petticoats, surrounding a central hole in which the plug is attached, by which it is fastened to the pole. The electricity passing on the wire, in its effort to get to the pole, if it were not for these aprons, would have sufficient power to arc through the air to the pole, at say thirty thousand volts. But by the use of these large aprons, it must traverse a much longer distance. That is the feature of the bell or petticoat insulator. The arcing consists of the electricity being transported across an

open space. In this case, it will follow the surface of a non-conductor rather than arc through the air. It almost invariably does this, and that is the reason why the bell insulator has such greatly extended surfaces. Does that answer your question, Professor?

Professor Orton: Yes, I think so. I would like to ask what is the relation between these bodies you have been exploiting here, and the general types of bodies in use in the electrical porcelain business. Have electrical porcelain manufacturers developed anything like a type for electrical porcelain, so far, or is each working for himself and keeping quiet?

Mr. Watts: Any man having a porcelain insulator standing fifteen or sixteen thousand volts feels that he has a gold mine, and will not let any information concerning it get out. Manufacturers having a material standing over that voltage have taken the greatest pains to prevent the composition of the body being known. I know of several instances where they have gone to ridiculous extremes to keep the matter secret. The bodies of high resisting porcelains in use in the United States, so far as I am familiar with them, use potash almost exclusively as the flux. Some few may contain a small quantity of lime. The tests I have made strengthen my belief, that a potash-lime porcelain is better able to endure strains than pure potash porcelain. You must understand that insulators are required to carry an immense strain, because high tension currents are carried on very large heavy copper wires, and the blowing of the wind on this wire frequently breaks the head of a large insulator short off.

Professor Orton: Do you know whether a red burning clay of fine vitrifying qualities has ever been used for insulation?

Mr. Watts: I know of one instance where a buff-red clay has been used successfully. But as far as I know, it did not stand a test of more than about 80,000 volts, while the porcelain which I made for this same party stood a test of 120,000. I do not believe a red burning body would stand as severe a test as the white or true porcelain.

Professor Orton: Does the presence of iron in the porcelain form the weak spot? Would the electric current break through a ferrous or ferric silicate easier than through a potash silicate?

Mr. Watts: I cannot say. But I know that any tendency to small cavities in the porcelain weakens it remarkably in resisting strains. It must be thoroughly vitrified so that moisture cannot penetrate it. If the moisture penetrates it, it decreases its resistance very fast. Dr. Zimmer cited a case last year of a kaolin vitrifying at a very low temperature. I happened to have some of the same sort of clay myself, and I put a piece of the raw clay into the kiln, and fired it to cone 02 and it came out magnificently vitrified. I never saw a piece of porcelain break with a more conchoidal fracture, yet it was somewhat ferruginous.

Professor Orton: What I want to know is whether a body of that kind would have a high insulating character?

Mr. Watts: That I do not know. I do not believe from what I have seen that the presence of iron had any deteriorating effect on the body used. I know of a number of clays being used in electrical insulating bodies, which have quite noticeable iron specks in them; and while these are not segregated and are evenly distributed, at the same time there is no indication of a deterioration of the product, owing to their presence, unless there is a big bubble or cavity of some sort formed by them.

Mr. E. C. Stover: Year before last, when we were at the power plant at Niagara Falls, I got hold of the head electrician there and asked him some questions along this line, as regards the different make-up of porcelain insulators and their relative resistance to electrical current, and his reply was that it was a case of mechanical strength rather than a case of chemical constitution. He claimed that perfect glass would make a thoroughly good insulator, but it was not used, because it was not so strong as a good solid porcelain. And I think some of the tests given there show that point quite clearly, as regards mechanical strength.

THE USE OF LEAD ORES IN CERAMICS.

BY

H. A. WHEELER, E. M., St. Louis, Mo.

In the use of lead in raw glazes, fritts, or glasses, for obtaining low fusing points, or soft enamels, or a highly vitreous lustre, the usual compounds employed are the oxides, litharge (PbO) and minium or red lead (Pb_3O_4), or the carbo-hydrate, white lead ($2\,PbCO_3$, $Pb\,(HO)_2$), which are all artificial products. When obtained from reputable dealers they are usually reasonably pure, the impurities* seldom exceeding three per cent. and often less than one per cent.

They generally come fine enough for immediate use, without further grinding, and they can be used direct for either raw or fritted glazes. But they are liable to cause lead poisoning if there is a lack of cleanliness in their use, and they are expensive, costing from five to ten cents per pound, according to the quality, quantity and market.

The natural ores of lead frequently occur sufficiently pure that they can be successfully substituted for these manufactured compounds in most of the requirements of ceramics, while two them, the sulphate or anglesite and the sulphide or galena, are free from poisonous effects, which alone should cause them to be used wherever it is possible, in preference to the manufactured compounds. These ores, or natural compounds of lead, are:

Cerussite, or "lead dry-bone," or the carbonate of lead.

Anglesite, or "hard carbonates," or the sulphate of lead.

Galenite, or galena, or "mineral," or the sulphide of lead.

There are other lead minerals that can be found in museum collections, but they occur in too small quantities and are too scarce to interest the ceramist.

* The dry white lead, not ground in oil, is of course alluded to. It is far less apt to be adulterated with baryta, as often occurs in the oil-ground product.

The carbonate, or cerussite ($PbCO_3$), contains 83.5 per cent. PbO or oxide of lead (or the active fluxing constituent in all natural or artificial lead compounds) when pure, and it can be used raw or in fritts or fused glazes direct without further preparation than grinding. It is a soft white, grayish or brownish colored mineral, that has a non-metallic lustre, and is very friable or easily ground. It is found in very large quantities in many mines in the Far West, and, like the sulphate or anglesite, is found in the upper portions of the mine, but never in depth or below the water-level, where the lead always changes to the sulphide or galenite. Notable occurrences are found in Leadville and in Chaffee county, Colorado, at Bingham and Tintic, Utah, and at Eureka, Nevada. In the Mississippi Valley lead districts of Missouri, Iowa and Illinois, this carbonate ore is only found in small amounts, though occasionally in ample quantities to meet the requirements of the ceramist.

As found in nature, carbonate ore is usually so mixed with the brown oxide of iron (limonite) and sometimes clay and other silicates, as to be valueless in ceramics; but pockets of many tons occasionally occur of a white to light gray color, that carry less than 5 per cent. of impurities, and hence, could be substituted for the more expensive manufactured compounds in many cases. Like the artificial carbonate and oxides of lead, cerussite is poisonous if taken internally, or absorbed through the skin, if lead poisoning is possible by such means, which will be taken up later.

The sulphate or anglesite ($PbSO_4$) contains when pure 73.6 per cent of oxide of lead, and it can be used direct in raw or fused glazes after grinding. It is a soft white to dirty gray colored mineral that has a non-metallic or earthy lustre, is usually very compact and heavy, but grinds readily. It is found quite abundantly in the far West, often in the same mine with the carbonate; Aspen and Eagle River, Colorado, and Frisco, Utah, have produced large quantities. The Mississippi Valley lead districts only produce it in trifling amounts, usually as a dirty gray exterior or shell on the galena or sulphide.

The sulphate is less apt to be contaminated with iron and other impurities than the carbonate, and by careful hand picking one would frequently be able to sort out several tons in many of the mines, that would have less than 5 per cent. of impurities. The dirty, dark color that it frequently has would suggest gross impurities, but the latter will often be found to aggregate less than 3 per cent. in very unattractive looking material. In the writer's opinion, the sulphate of lead is not poisonous, which makes this salt a very desirable form to use, whether the natural or artificial sulphate is employed.

Galenite or galena or the sulphide of lead (PbS) contains 86.6 per cent. Pb of metallic lead when pure, or 95.3 per cent. PbO or oxide of lead when the sulphur (S) has been driven off in an oxidizing atmosphere such as is almost invariably used in ceramics. Before the lead oxide in galenite or the sulphide of lead is available, it is necessary to roast and drive off the sulphur with which it is combined, which is accomplished by heating it to a red heat with an excess of air. As this is the condition of about all kilns or muffles when being heated, the galena or sulphide can be used direct in raw glazes, as the sulphur will roast and be driven off by the time the glaze has melted. But in fritting or fusing in crucibles, where the air is more or less completely shut off, galena or the sulphide can not be used, as most of it will melt and settle to the bottom as a matte in a raw or uncombined condition, since the silicic, boracic or phosphoric acids that all glazes depend on to make them fusible, are not able to decompose the sulphide of lead, and, therefore, the sulphur is not expelled. Where it is possible to use such oxidants as potash or soda nitre in the charge, the sulphur is expelled or else converted into the harmless SO_2 condition, and this valuable lead salt can then be employed for fused glazes, as all the lead is then rendered available. *

* If nitre is used to drive off the sulphur in galena, care must be exercised to not heat the charge too rapidly, least the combustion of the sulphur causes such a rapid evolution of SO_2 or SO_3 gases as to result in the charge boiling over.

Galena or galenite is a bluish-gray, metallic, very heavy mineral that is very brittle and quite soft. It occurs very abundantly in most of the mining districts of the far West, where it is usually far more valuable for its silver than its lead, as it may contain from 20 to 500 ounces of silver per ton, which is true of all western lead ores, whether sulphide, sulphate or carbonate. In the Mississippi Valley it is free from silver, while it usually occurs purer than in the far West, and it is very abundant, from the ceramic standpoint, in southeastern, central and southwestern Missouri, northwestern Illinois, southeastern Wisconsin, and northeastern Iowa. Excepting in southeastern Missouri, the galena is usually associated more or less intimately with zinc and iron minerals, that would gravely interfere with its ceramic value.

In the southeastern Missouri district, of which St. Louis is the outlet, the lead occurs in two radically different forms or types of deposits, known as the "disseminated" and "surface" mineral. The "disseminated" type of galena deposits occurs notably in St. Francois county, where the lead is found as a very low grade ore finely scattered or disseminated in a magnesian limestone. This is crushed and concentrated by water in mills to a product that will assay from 60 to 75 per cent. lead, the practice varying at the different mills, so that there are still 12 to 20 per cent. of impurities, which is mainly fine magnesian limestone of quite uniform character. There is a product that comes from the setting boxes of the slime machines in the concentration mills that is in a very fine condition, and which in some of the mills will assay 75 to 78 per cent. of lead, and which would be the most attractive material for the ceramist from this district.

The "surface" type of galena is mainly found in Washington and Jefferson counties, and Palmer and Potosi are the principal producing points. This surface or "block-mineral" consists of large cubes and chunks of galena that are found in the ferruginous or red surface clays, and which after a limited amount of picking with a cleaning hammer, or washing with a hose or water-bucket, will assay 80 to 85

per cent. in lead, or contain only 3 to 8 per cent. of impurities. By specifying a *specially selected* or extra clean mineral free from clay, carload lots of this coarse, lump galena can be secured that will assay 84 to 85.5 per cent. lead, or contain only 1½ to 3 per cent. of impurities, or pure enough for almost every use of the ceramist. The usual prices of the market run of this "surface" galena vary from $40.00 to $50.00 per ton, while by paying one-half cent. a pound extra, the very pure extra clean mineral that assays about 85 per cent. lead can be secured at, say three cents per pound, which is the richest lead compound on the market, excepting the two oxides minium and red lead, and by far the cheapest.

The galena or sulphide of lead is not poisonous from absorption through the skin and *probably* is not, when taken internally. The writer has strong doubts whether the lead poisoning, so frequently found among painters, lead-glaze dippers, lead smelters, etc., is ever due to absorption through the skin. For while the hands of this class of workmen are frequently more or less covered with oxide or carbonate compounds of lead, which would permit of its ready absorption through the pores, an intimate acquaintance with lead workers, leads the writer to believe that the lead is introduced into the human system by the food and tobacco that is handled by these same lead-befouled hands. It is a most painful fact that familiarity causes such men to become very careless and indifferent to the evils of lead poisoning, so that a man will sit down and eat his lunch without taking the trouble to first wash his hands, although they may be grimy with lead. The constant handling of tobacco, also, without any effort to protect the surface from contamination is a prolific source of trouble. Even where the wash basin is freely used, the dirt under the finger nails is seldom carefully attended to, and while this source of poisoning the food does not operate so rapidly as the unwashed hand, it is always loaded, and slowly but surely gets in its disastrous cumulative work. It is especially this source of contamination that causes the writer to doubt the poisonous character of galenite when taken internally, since his experience with many hundreds of workers in the lead mines and

concentration mills has failed to show any poisonous results. Yet, as soon as this sulphide is converted more or less freely into carbonate and oxide in the roasting and smelting furnaces, lead poisoning becomes extremely common among the same class of men, although the lead miners are even more careless than the lead smelters about washing their hands before eating. It would therefore seem that the lead mine workers probably take considerable more lead into their system in the course of a year than the lead smelters; but as it is in the form of galenite or the sulphide, which is insoluble, and as the gastric juices seem to have no effect on it, it seems to pass through the system and is promptly thrown off without producing any poisonous effects, or accumulating in the manner which makes the oxide and carbonate forms of lead so dangerous.

The writer further believes that the sulphate of lead, whether natural or artificial, is as free from poisonous action as the sulphide, as it is a salt of even greater insolubility; but his personal experience is not so extensive with this salt of lead. The writer is well aware of many lead mines in the far West that are most disastrous on the health of the miners, from the different forms of lead poisoning that result from working in them. In one case in Utah, from four to six weeks was as long as a man could withstand it, before being returned to the hospital. While in some of these cases, the sulphate or anglesite ore occurred, the writer always found it freely associated with the cerussite or carbonate, and, in the very dangerous mines, it was always the carbonate form. As these oxidized forms of lead ores are only found in *dry* mines, the severely poisonous character of such mines is usually due to the lead dust that floats in the mine atmosphere, resulting from the blasting, especially as lead ore is a favorite tamping for the blast holes.

The writer warmly commends the sulphide or sulphate compounds of lead to the ceramist to avoid the evils of lead poisoning, and as the sulphate will be found preferable, if not essential, in all crucible work, the artificial sulphate should be used if a satisfactory quality of the natural cannot be procured.

DISCUSSION.

Mr. Hensel: We are aware that American factories are consuming vast amounts of raw lead glazes, and it seems to me it would be of interest to discuss this question. In Germany, dealers in ceramic materials advertise that they have lead ores of high grade for sale which are reliable. We have nothing of that kind in America, and in buying lead ore for ceramic purposes we have to take the chance of getting a good grade. That is a great drawback. It seems to me that if those owning lead mines and putting the ore on the market would take some pains to learn what we need, and to supply a strictly uniform article, they could easily build up a very satisfactory branch of trade which is now entirely overlooked.

Professor Orton: I do not know whether Professor Wheeler is prepared to prove his statements or not, as to the non-poisonous quality of galena. If it can be proven by a collection of medical testimony, or by any other means such as doctors employ to find out such facts, it would be a valuable thing to know. And further, if we should use the sulphide of lead, as Professor Wheeler suggests, as a glaze ingredient, we would only be going back to the original practice of the English potter. The poisonous character of lead glazed ware in the beginning was due to the fact that the potter supplied no silica or alumina with the lead, which took up from the body itself enough to more or less completely satisfy its needs. Now, you can readily appreciate the fact that where the potter dusted powdered galena on a freshly thrown piece with his hands, he would get it very uneven, thick in some places and thin elsewhere. Where the glaze was thick, it was basic, and where it was thin, it satisfied itself with silica and alumina from the body. So those old English crocks were sometimes safe, and sometimes they were not. In consequence, all lead-glazed crockery came into very ill odor in England. But the ease with which glazes can be made with lead has caused potters to resist all attempts to down it by legislation in England and elsewhere, and it is still used and likely to be used.

The question is, cannot this suggestion of Professor Wheeler find a proper reception among individuals using lead glazes for the cheaper line of products—architectural products, glazed brick, the lower grades of floor or wall tiles, such as are used in foreign countries on a large scale, roofing tiles, &c. Why could not these industries use galena, and obtain a glaze which would be good enough for their purposes? It is not necessary that a crude architectural product have a glaze as fine as dishware, which is to be scrutinized at close range.

Mr. Hensel: Galena gives us as good a glaze as any other form for such wares as roofing tile.

Professor Orton: I never saw it tried, bnt I am glad to hear Mr. Hensel say that. I suppose the only objection would be the sulphur, but if that were properly roasted out, there is no reason why the lead oxide remaining is not as good as if introduced from any other source.

TIN OXIDE IN CERAMIC FLUXES.

BY

STANLEY G. BURT, CINCINNATI, O.

The main object of this paper is to determine whether any stannic oxide is soluble in a glaze and not to discuss tin enamels in general, as might be supposed. It is customary among potters to consider tin oxide as wholly insoluble in a glaze. The glaze in its fused state is thought to be unable to dissolve the tin at all, the particles merely floating in it, or as we say, being held in suspension.

It may possibly not be strictly correct to speak of a glaze forming a solution, since we form solutions of solids or gases by dissolving them in a liquid, so a glaze which when cooled is a solid, could not form a solution. However, right or wrong, it is the constant practice to speak of a substance as soluble or not in a glaze, by which we mean that on adding this substance to our glaze, we either have a clear transparent glaze or else we have the substance undissolved, held in suspension, and an opaque glaze or enamel resulting.

This being understood, it will be plain that our ability to make a tin enamel must rest upon its insolubility in the glaze flux. Now the points to be considered in this paper are, *first*, is it completely insoluble, and *second*, is it insoluble as the dioxide, or does it undergo some chemical change?

In these days we can no longer speak freely of substances as insoluble or infusible. Flint and carbon are now fused, and German chemists make elaborate analyses of the amount of glass dissolved by water. So it seemed quite possible that a certain percent of tin oxide might be soluble in a glaze.

If we turn to the subject of tin in our chemistries, we find that stannic oxide is infusible and insoluble in acids and alkalies, but when fused with sodium hydrate it yields a

stannate, soluble in water. Tin is one of the intermediate elements that act as acids toward strong bases, and as bases to strong acids, so we have sodium stannate, and stannic chloride. Careful research through such works as were at my command, failed to throw any light on the subject of this paper.

It is quite obvious that the first thing to investigate is whether this tin oxide was absolutely inert in ceramic fluxes. That is, whether some chemical change takes place in the oxide when fused in a ceramic flux, even though it be insoluble in its changed form.

A word in explanation of what I mean by a ceramic flux. In these, I include glazes and their low fusing ingredients considered separately, and exclude such fluxes as are not ordinarily used in ceramics. We know, for instance, that the oxide of tin fused with sodium hydroxide yields a soluble salt, but sodium hydrate is not used by potters, and hence is not a ceramic flux.

Before testing the oxide in actual glazes, I made a few tests, trying first boracic acid calcined and uncalcined. As there was no alkali in this, there was no chance of forming a stannate, and so far as my knowledge goes, we have yet to form a tin borate. Still, I was anxious to see whether there could be any action at all, and was rewarded by an interesting result. I took first the flaky boracic acid, which in heating, melts in its water of crystalization, boils and gradually loses this water, requiring a high temperature to do so completely, and finally leaving as a result, a fine clear glass. The formula for this acid is B_2O_3, 3 H_2O. With the water driven off in calcining, we have left the B_2O_3. Now, to 1. Eq. of the flaky acid, I added 0.004 equivalents SnO_2. The fusion takes place as before, but the result is a fine white enamel. The interesting point is that I believe the stannic oxide has undergone a chemical change, for while the regular oxide is so completely insoluble, this enamel that I got was soluble in HCl, from which solution the Sn was precipitated as the orange sulphide with sulphuretted hydrogen. We had B_2O_3, 3 H_2O and added SnO_2. Is it possible that stannic acid (H_2SnO_3) is formed? It is hardly

possible that the acid could exist at a high heat without dissociation. The water of crystallization is, however, a necessary part of the reaction, for on testing, the calcined boracic acid was unable to show any action on the oxide at all.

In repeating my experiments, to test my results, I found some difficulty in reproducing this reaction with the flaky acid, and as my time was too limited to determine the cause of error, I would not give this test here at all, except for the possible light it may throw on the different appearance of the two enamels. That is, on contrasting the enamel formed from the calcined acid with that from the non-calcined, we find that in the former the actual particles can be noticed in suspension, while in the latter they are altogether too fine to be distinguished. It has, in fact, quite the look of a precipitate.

Borax was next tried. Here we introduce sodium into our equation. The borax on fusing acts much the same as the boric acid; that is, it melts, gives off its water of crystallization, the result being finally the well known clear bright glass. On adding the stannic oxide to it, however, the action is entirely different. In the first place, I was unable to produce the voluminous white enamel produced with the flaky acid, but on the other hand I was here able to produce a perfectly clear solution of the tin in the borax. We have in borax Na_2O, 2 (B_2O_3), 10 H_2O. To this we add SnO_2. I would like to have shown the same effect from the water of crystallization as shown with the acid, but there is less actual boiling, if I may so call it, and the swelling of the borax gives less chance for action on the tin in that state. What we do form here seems to be the sodium stannate, $Na_2\,SnO_3 + 2\,(B_2O_3) + 10\,H_2O$, which gives a clear solution. Naturally, if too much tin is taken, the flux will be unable to dissolve it all, and the excess will be merely held in suspension, and an enamel will result. I was able to dissolve 0.0129 Eq. SnO_2 in 1. Eq. of Borax. This is of course far below what the formula calls for, but the action is very slow, and a prolonged fusion would be necessary to determine just how much could be dissolved.

Calcined borax acted equally well, showing that the water of crystallization is not a factor in this reaction. I feel justified in assuming the formation of Na_2SnO_3 here, for if there was any chance of a tin borate being formed, that would occur with the boracic acid.

Here we have a clear case of the complete solution of a certain per cent of the stannic di-oxide in a ceramic flux. That is, in this flux, we have converted it to a stannate which was soluble.

Those of us familiar with color-making know that in certain receipts for the tin-chromium-pink color, borax plays a leading part; that is, its action on the tin enables us to form the color. I have here a sample of borax and tin, fired together without any chromium, in which you see the distinct formation of a lilac color.

We know that by fusing the tin oxide with NaOH, we have a ready means of forming the sodium stannate. While, as before stated, NaOH is not a ceramic flux, Na_2CO_3 is, so it seemed of interest to determine what its action would be. When fused alone, Na_2CO_3 will not give a clear glass on cooling, so it is impossible to see in what form the tin fused in it is present. The mass resulting from this fusion is only partially soluble in water. In this solution I could find no tin, but the total mass was soluble in HCl. In just what form the tin is present here, is hard to say. Its not being soluble in water would indicate that it was not the stannate. What is plain, however, is that we have here another ceramic flux which acts directly on the tin oxide.

As a final preliminary test, I added SiO_2 to the Na_2CO_3 until all effervescence ceased, forming thereby, sodium silicate. Now, to this I added tin oxide, aiming to determine thereby whether this silicate would have any action on the tin. I found that the action there was practically the same as with the carbonate — partial solution in water, complete solution in HCl. The tin easily precipitated as orange sulphide with sulphuretted hydrogen. This is a most important test. All glazes are silicates. Therefore, if in a silicate there was no direct action on the oxide, this

investigation would necessarily be much more complicated. We would very possibly be ruled out of court as having no case.

We would have to show that the tin went into an early combination, and in that way was soluble in the silicate flux. Failing in this, a careful investigation of various silicates would be necessary, a long and difficult problem. Fortunately, this is not necessary, as this test shows that the oxide of tin is not an inert substance in a silicate flux, and further we have shown that in the presence of borax, it may go into a complete solution. My next tests show that even without borax, we may get a complete solution.

I now tested two regular glazes with the stannic oxide. The first, a fritted glaze, having 1. equivalent B_2O_3, the second, a raw lead glaze, having no B_2O_3. To these I added the SnO_2, starting with 0.01 equivalent and running up to 0.25 equivalent. I have samples of these with me, and would be glad to have the members examine them. In the raw lead glaze, the 0.01 equivalent seems to be completely dissolved, while with 0.02 we can easily see a trace remaining. The 0.25 equivalent gives a complete enamel. In the fritted glaze not only is the 0.01 completely dissolved, but as far as I can determine, 0.02 has also gone into solution. It is therefore probable that the average glazes dissolve at least 0.01 equivalent of tin oxide.

The enamels formed by these two glazes are quite different. While the fritted glaze forms a fair enamel the raw glaze has a curdled look, and the small particles of tin are easy distinguishable. One of the points I hoped to prove in this paper, was my belief that certainly some of the tin was first dissolved and then precipitated in a true enamel. In speaking of the enamels from the calcined boracic acid, and that from the un-calcined, I called attention to the fact that while the former showed the particles in suspension, the latter had the true milky character. Much the same effect is noticed in the enamels from these two glazes. However, this is merely theory, for which as yet I have been unable to gather sufficient proof, so I will not dwell upon it further.

It may be asked what the direct practical value of such an investigation is. This question of the solubility of tin oxide was raised in a discussion of crystalline glazes. We know that certain elements combine with silica to form amorphous silicates, which give a clear glass or glaze. Now this combination takes place at a high heat. Hot liquids, as a rule, are able to hold in solution a greater per cent. of salt than cold ones, so that we often have a clear hot solution from which salts crystallize out on cooling. The same seems to be true of a glaze. While at its maximum heat, a glaze may be clear, even if supersaturated with certain elements. On slow cooling these may crystallize out, forming at times very beautiful results. We have been able to produce this effect from a number of elements, as for instance, zinc, iron, copper, chromium, titanium, but others remain to be investigated. If we are ever to attempt any such result from tin, we must of course first show that the silicate flux has a solvent action on the tin oxide, second, a proper super-saturated solution must be formed, and third, this must be tested with the careful cooling required by other crystalline glazes.

I feel that the first step has been accomplished, as it has been shown that a certain per cent. of tin is soluble in a glaze. The formation of a proper super-saturated solution should next be tried. As the sodium stannate is shown soluble in borax, it is possible that a super-saturated solution of this, added to a fritt under proper conditions, might lead to satisfactory results.

DISCUSSION.

Mr. Stover: (Placing on the blackboard the following formula:)

$$\left.\begin{matrix} .60\ CaO \\ .36\ K_2O \\ .04\ SnO_2 \end{matrix}\right\} 0.5\ Al_2O_3,\ \ 4.00\ SiO_2 \qquad \text{(At Cone 12)}$$

There is a formula of a tin glaze which matures properly, making a good opaque glaze, at cone 12. The tin oxide in this glaze figures out about 1.5 per cent.

Mr. J. W. Hasburg: A paper involving such questions in chemistry is not very easy to discuss off-hand, but I will state some observations made by me a long time ago on tin glazes.

As stated by Mr. Burt, sodium and tin oxides in proper proportions form sodium stannate, a definite chemical compound soluble in water. Boracic acid and tin oxide in any proportion does not form a chemical compound, as all the boracic acid can be dissolved out, leaving the tin oxide unchanged, which shows that no chemical union has taken place. If, however, an alkali is added to this boracic acid-tin mixture, the tin will be dissolved in proportion to the alkali added.

Tin oxide is the most difficult oxide to dissolve in a silicate, and when more tin oxide is present than the alkali will take up, the mass becomes opaque; sometimes it comes from the fritt fire almost clear, and only becomes opaque after reheating.

On a close examination, it will be found to have a crystalline structure. If other bases having a greater affinity for alkaline silicate, or which dissolve more readily in it, are present, it will not require so much tin oxide to make this silicate opaque.

Titanic oxide acts very much the same as tin oxide, and other bases will also make opaque mixtures if added in excess, but they may require annealing to bring out the opacity and cause crystallization.

The opacity of tin glazes is due entirely, in my opinion, to the tin being in suspension.

The amount of tin oxide in the above formula is small on account of the alkaline silicates being saturated with other bases, which combine with the silicates more readily than tin oxide.

Mr. Hensel: Schumacher states that a lilac color like that which Mr. Burt shows is very often due to a combination of lime, tin and iron. A very small quantity of iron is all that is needed to develop the color.

NOTE ON THE RELATIVE POINT OF DEHYDRATION OF PURE AND CALCAREOUS CLAY.

BY

WILLIAM M. KENNEDY, BEAVER FALLS, PA.

The first experiment on this subject appearing in an American publication, was one performed by Mr. A. E. Barnes. It appeared in the "Clay Worker" for June, 1895. The incompleteness of Mr. Barnes' work was due to his having used a Brown pyrometer of the expansion bar type, the temperature limit of which is about twelve hundred degrees Fahrenheit. The dehydration period is generally construed to include, not only the driving off of the combined water from pure clay, but also the expulsion of CO_2SO_2, etc., from impure clays, such as calcareous or limey clays, ferrugineous clays and the like.

In this experiment I have made a comparison of two of these clays, namely, pure clay and calcareous clay.

I prepared two series of brickettes. The first series was made by grinding in a ball mill 3000 grams of "Florida kaolin," running this slip through a 150 mesh sieve and drying in plaster moulds. The clay was then thoroughly wedged and kneaded and sixty brickettes were made. The brickettes were moulded in the form of elliptical discs with rounded edges, about three-eighth of an inch in thickness and weighing in the neighborhood of thirty grams each. A one-fourth inch hole for inserting wire for removal from the kiln was made in each brickette, and each was carefully stamped with a number for identification. When thoroughly dry, the brickettes were carefully sponged, and polished with a cloth, to prevent loss in weight by chipping of corners and edges in handling.

The other batch of material had the following composition:

Florida Kaolin	70 parts.
Whiting	30 "
	100 parts.

This material was mechanically treated, moulded into brickettes, dried, marked and polished in the same manner as the first batch.

The dried brickettes were heated for one hour in an air oven at 130 degrees C. They were then cooled in a dessicator, and rapidly weighed to prevent absorption of hygroscopic water. The accuracy of weighing was to one milligram. The brickettes were then placed in a muffle in a down draft kiln. A fire-clay tube, three inches in diameter, containing the porcelain tube and thermo-couple of the Le-Chatelier pyrometer was laid lengthwise through the centre of the muffle, and the kaolin brickettes were now piled up on one side of the tube, and the kaolin-lime brickettes on the other side. The distance of the brickettes from the outside of the muffle was about twenty-four inches, and was in the centre of the heated area and well protected from drafts of cold air. The front of the muffle was left open, and opposite it, two large peep holes were left in the wicket, through which it was easy to reach in with a wire and remove the brickettes.

The brickettes being placed in position, the kiln was started. The temperature was carefully noted at every 50 degrees from 100 degrees to 300 degrees, and two of each kind of brickettes were withdrawn at each temperature reading, cooled at a dessicator and weighed. From 300 degrees to 850 degrees brickettes were withdrawn at every 25 degrees. From 850 degrees to 1000 degrees, the completion of the burn, brickettes were removed at every 50 degrees.

The time occupied by the experiment was twenty-eight hours. The temperature was increased as steadily and regularly as possible until 725 degrees was reached, when this heat was maintained as near as possible for a trifle over twelve hours, to observe the effect of heat-soaking on the brickettes. The temperature was then raised rapidly to 1000 degrees.

During the early stages of the burn difficulty was experienced in seeing the brickettes in the kiln, and a bicycle lamp was used to project light into the dark muffle. From 575 degrees up to the completion of the burn, no trouble was

experienced from this cause. In the early stages of the burn, the brickettes were sooty; this disappeared at 475 degrees in the calcareous clay brickettes, and at 500 degrees in the kaolin brickettes. When weighed after removal from the kiln, this soot was removed to as great an extent as possible with a fine "camel hair" brush. At 525 degrees the clay-lime brickettes showed a faint red glow. The kaolin brickettes did not show evidence of becoming "red hot" until 550 degrees was reached.

ANALYSIS OF THE RESULTS.

Taking the kaolin brickettes first, it will be observed (Plate I, black line,) at 150 degrees, the temperature at which the first observation was made, that only .018 per cent. of loss had occurred. From here to 450 degrees the loss was gradual, only amounting to 1.59 per cent. At this point, the brickettes began to lose weight rapidly. This rapid loss continued until a temperature of 600 degrees was reached, when 12.1 per cent. loss had occurred. From 600 degrees to 725 degrees the loss was again very gradual, the temperature was held near 725 degrees for about twelve hours in order to observe the effect of soaking on the expulsion of water. This, as it will be observed, was very slight, only .07 per cent. of loss occurring from this temperature to the end of the burn. Small losses occurred at each observation, aggregating in all only .54 of one per cent. The total loss was 13.84 per cent. and the dehydration period, or the temperature between which the bulk of the combined water, was driven off can with safety be said to lie between 450 and 600 degrees centigrade.

Now taking up the kaolin-lime brickettes (Plate I, broken line) the losses will be observed to be very slight up to 450 degrees. At 475 degrees but very little additional water had been expelled from these brickettes. From here to 600 degrees the rate of loss coincides almost exactly with that of the kaolin brickettes. As 600 degrees represents the close of the dehydration period, the losses from here on are due to the expulsion of CO_2 gas. The dotted line extending from 8.97 percent at 600 degrees to 9.7 percent at 1000

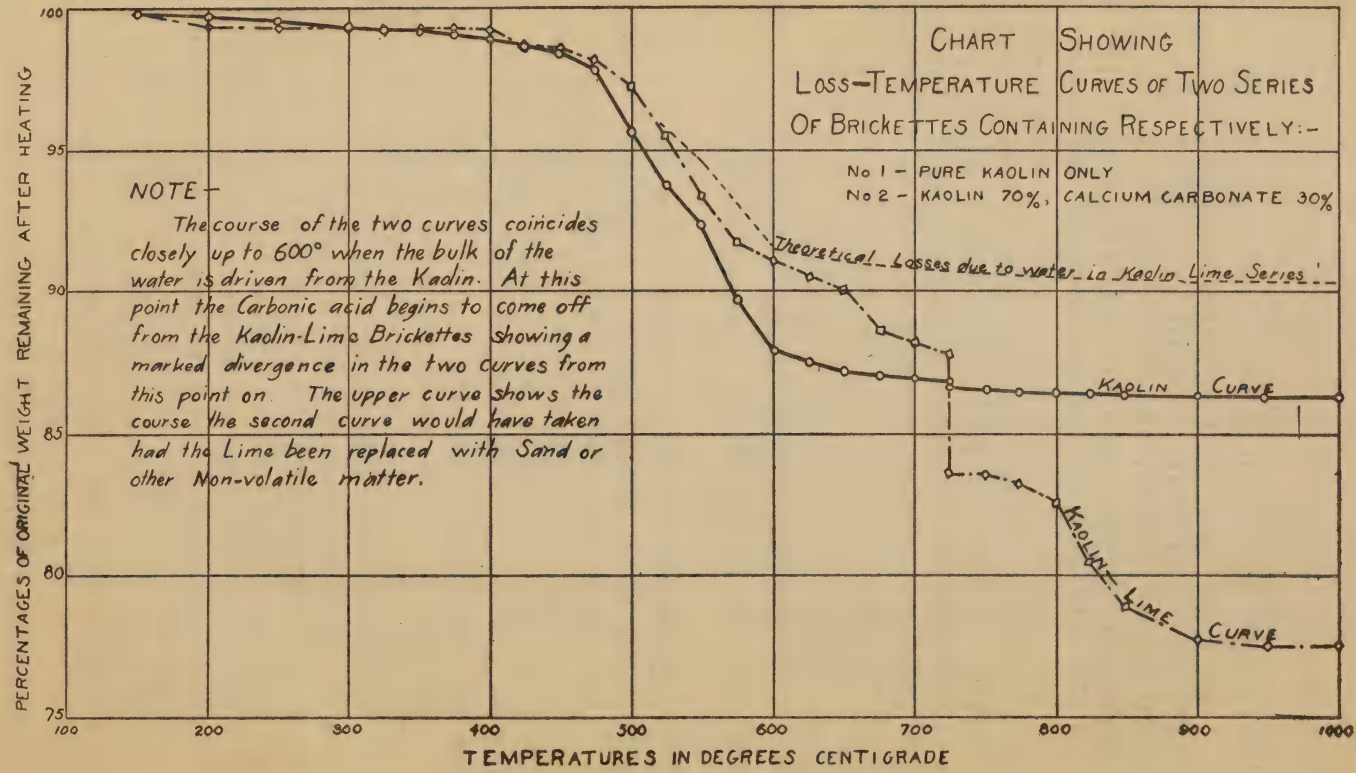


CHART SHOWING
LOSS-TEMPERATURE CURVES OF TWO SERIES
OF BRICKETTES CONTAINING RESPECTIVELY:-
No 1 - PURE KAOLIN ONLY
No 2 - KAOLIN 70%, CALCIUM CARBONATE 30%
NOTE -
The course of the two curves coincides closely up to 600° when the bulk of the water is driven from the Kadin. At this point the Carbonic acid begins to come off from the Kaolin-Lime Brickettes showing a marked divergence in the two curves from this point on. The upper curve shows the course the second curve would have taken had the Lime been replaced with Sand or other Non-volatile matter.
Theoretical Losses due to water in Kaolin Lime Series
KAOLIN CURVE
KAOLIN LIME CURVE
PERCENTAGES OF ORIGINAL WEIGHT REMAINING AFTER HEATING
100
95
90
85
80
75
100
200
300
400
500
600
700
800
900
1000
TEMPERATURES IN DEGREES CENTIGRADE

degrees represents the theoretical loss of the remainder of water in the kaolin-lime brickettes. From 600 degrees to 725 degrees, the expulsion of CO_2 was almost as rapid as that of the water had been. 12.2 percent loss had occurred up to this point. The soaking period of 12 hours at this temperature shows a decided loss in the kaolin-lime brickettes—4.1 percent out of a total of 22.5 percent; but for the next 125 degrees raise in temperature very little loss occurred. From here to 900 degrees the loss was again rapid, 22.3 percent having occurred at this temperature. From here on to the end of the burn (1000 degrees) only 0.2 percent loss was found. This series of brickettes proves that while the water of dehydration in kaolin is expelled between 450 and 600 degrees, the CO_2 in brickettes containing 30 percent lime will prolong the dehydration period to 900 degrees. It also shows that heat soaking for a comparatively long period is of no advantage, because while it does drive off some of the CO_2, it does not drive off all of it, and the end of the dehydration occurs at the same temperature as if no soaking had been given.

Plate II was drawn for the purpose of showing what took place during the soaking period at 725 degrees.

The solid black line shows the time-loss curve of the kaolin brickettes. It will be observed that the bulk of the water was driven off in less than two hours, or between five and seven hours after lighting the kiln; and it will also be observed that the soaking period had very little effect on the brickettes. From 8 hours and 55 minutes to 28 hours the curve line is almost straight with a total loss of 1.74 percent during the period.

With the kaolin-lime brickettes it is quite different. It will be observed (broken line) that the loss continued at a fairly rapid rate during the whole of the burn, and that during the soaking period, 11 hours and 30 minutes to 24 hours, there was a loss in weight of 4.1 percent.

The following tables show my observations as recorded:

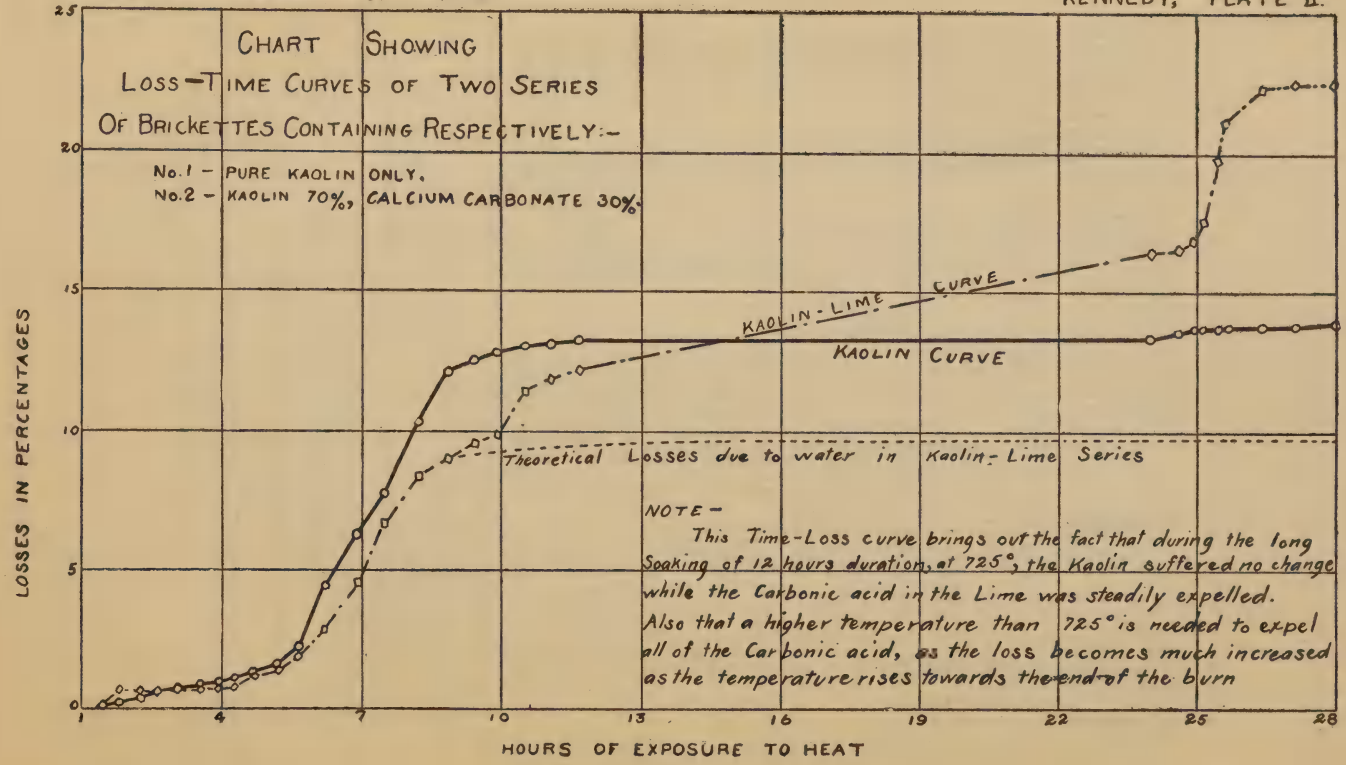


CHART SHOWING
LOSS-TIME CURVES OF TWO SERIES
OF BRICKETTES CONTAINING RESPECTIVELY:-
No.1 - PURE KAOLIN ONLY.
No.2 - KAOLIN 70%, CALCIUM CARBONATE 30%.
KAOLIN-LIME CURVE
KAOLIN CURVE
Theoretical Losses due to water in Kaolin-Lime Series
NOTE -
This Time-Loss curve brings out the fact that during the long Soaking of 12 hours duration, at 725°, the Kaolin suffered no change while the Carbonic acid in the Lime was steadily expelled. Also that a higher temperature than 725° is needed to expel all of the Carbonic acid, as the loss becomes much increased as the temperature rises towards the end of the burn
LOSSES IN PERCENTAGES
0
5
10
15
20
25
1
4
7
10
13
16
19
22
25
28
HOURS OF EXPOSURE TO HEAT

TABLE I.

PERCENT LOSS VS. TEMPERATURE.

Percentages of Loss in Kaolin Brickettes.				Percentages of Loss in Kaolin-Lime Brickettes.			
Temp. at Drawing	First Brickette.	Second Brickette.	Average.	Temp. at Drawing	First Brickette.	Second Brickette.	Average.
150	.006	.027	.018	150	.27	.075	.18
200	Chipped	.026	.026	200	.66	665	.66
250	.53	.29	.41	250	.58	.74	.66
300	.69	Chipped	.69	300	.67	1.22	.67
325	.73	.72	.72	325	.45	1.95	.71
350	.75	.75	.75	350	.55	.86	.71
375	.93	.95	.94	375	.77	.66	.71
400	Chipped	1.11	1.11	400	.44	1.13	.77
425	1.43	1.21	1.32	425	1.49	1.28	1.38
450	1.10	2.09	1.59	450	1.68	.935	1.41
475	2.41	2.10	2.25	475	Bad	1.84	1.84
500	4.45	Chipped	4.45	500	3.07	2.51	2.79
525	6.60	6.00	6 30	525	4.53	4.54	4.54
550	Bad	7.75	7.75	550	6.85	6.51	6.68
575	10.30	Chipped	10.30	575	8.20	8.55	8.35
600	12.10	12.10	12.10	600	8.54	9.40	8.97
625	12.60	12.45	12.52	625	9.53	Chipped	9.53
650	12.90	12.74	12.82	650	Chipped	9.90	9.90
675	12.90	13.10	13.00	675	11.40	Chipped	11.40
700	13.10	Chipped	13.10	700	Chipped	11.82	11.82
725	13.25	13.21	13.23	725	12.20	12.20	12.20
725	13.50	13.20	13.30	725	16.40	16.30	16.40
750	13.31	13.70	13.51	750	16.50	Chipped	16.50
775	13.58	13.65	13.61	775	17.10	16.40	16.80
800	Bad	13.65	13.65	800	17.30	17.60	17.45
825	Broken	13.67	13.67	825	20.00	19.52	19.76
850	13.70	13.60	13.70	850	21.20	21.00	21.10
900	Chipped	13.75	13.75	900	22.20	22.40	22.30
950	13.75	Chipped	13.75	950	22.50	22.50	22.50
1000	13.84	Bad	13.84	1000	22.40	22.54	22.50

TABLE No. II.

PERCENT LOSS VS. TIME.

Kaolin Brickettes.	Kaolin-Lime Brickettes.	Hours.	Minutes.
.018	.18	1	25
.026	.66	1	45
.46	.66	2	13
.69	.67	2	40
.72	.71	3	00
.75	.71	3	25
.94	.71	3	50
1.11	.77	4	15
1.32	1.38	4	45
1.59	1.41	5	15
2.55	1.65	5	40
4.45	2.79	6	15
6.30	4.54	6	50
7.75	6.68	7	35
10.30	8.35	8	15
12.10	8.97	8	55
12.52	9.53	9	25
12.82	9.90	9	55
13.00	11.40	10	30
13.10	11.82	11	10
13.23	12.20	11	50

Soaking period of 12 hours duration, during which no gain of temperature occurred.

13.30	16.40	24	00
13.51	16.50	24	40
13.61	16.80	24	55
13.65	17.45	25	10
13.67	19.76	25	25
13.70	21.10	25	40
13.75	22.30	26	10
13.75	22.50	27	20
13.84	22.50	28	00

DISCUSSION.

Mr. W. P. Gates: I have had some experiences in this line myself in our kilns. I used a natural limey clay, and I started drawing my trials much earlier. All were dried at 120° C. and placed in the kilns. On drawing up to about 150° C., the trials showed a decided gain in moisture, the highest amounting to four or five per cent. This gives a pretty good indication that a good deal of fuel could be lost from overdrying the wares. I think many plants dry their ware too much, whereas they could save by underdrying, and letting some of the moisture be taken off in the kiln, as the test showed that it had to be done over again in the kiln in any case.

Mr. Alfred Yates: My experience teaches me that you cannot get the ware dry enough; the dryer you set it, the better results you get.

The Chair: We all know that there is a large amount of water vapor in the kiln in the early stages of burning, and it would seem reasonable that an over-dried clay would re-absorb some of it.

Mr. Yates: I think that good burning requires a low temperature and good circulation in the kiln in the beginning. By this, you get even distribution. If you push it, you will have hot places and cold places, and the hot places will rob the cold places, and prevent equalizing over the whole area. But, if you will hold down the temperature, and keep up the circulation, you will get uniformity from the start.

Mr. W. P. Gates: I was speaking only of muffle kilns. This test of mine was run in a small muffle kiln. I do not know how it would run in an open kiln.

The Chair: The point in the paper is the comparison between clay with lime, and clay without it. Most of us have to deal with lime-bearing clays sometimes, and their behavior is decidedly interesting.

I would like to ask about the condition of the kaolin-lime brickettes at the close of the burn. Was there any difference in hardness?

Professor Orton: The lime-brick or the calcareous mixture was much more porous, of course, at the end of the burn than the kaolin was, because vitrification involving so large an amount as thirty percent of lime would not occur at so low a temperature; so the lime mixture was a good deal softer. If the temperature had gone higher, it would have been harder than the kaolin. So far as I know, the presentation of these facts here is the first time in which a pure clay has been compared with a calcareous clay in the matter of its dehydration curve; and it shows us a very interesting fact, viz., that the calcareous clay is ready for vitrification changes, and for the perfection of its heat reaction at 900°; while the clay-substance is practically ready from six hundred on. There is a stage in the dehydration period in which the gases are coming off the clay rapidly, which can be prolonged three hundred degrees by the presence of carbonate of lime. Two students in the university are now at work on a similar curve, in which ferrous carbonate is being experimented on in connection with kaolinite; the idea being to attempt to prove the point at which CO_2 is being expelled from $FeCO_3$. That is a more practical experiment, because clays containing thirty percent of lime are not commonly used. But clays containing ferrous oxide are in common use, and are especially subject to "black-coring," swelling and numerous other defects. Therefore it seemed to me quite important to show at what point a ferrous carbonate brick was ready for further combination, and so I assigned this problem to these students. This investigation of Mr. Kennedy's seems to me of equal value in a way, though not so directly applicable to conditions in this country.

THE MANUFACTURE OF ARTIFICIAL SAND STONE.

BY

SAMUEL V. PEPPEL, B. Sc., Columbus, O.

During the last five or ten years, occasional newspaper articles written in popular vein have appeared describing a wonderful industry which was to revolutionize the brick business in this country, intimating that brick to answer all purposes were to be made from sand at a cost far below that of ordinary clay brick. Time has not verified these statements, in this country at any rate. Nevertheless, the sand brick industry has a promising future in this country, for the production of ornamental architectural effects, if for no other purpose.

Sand brick, or the "kalksandstein" of the Germans, is a mass of sand particles bound together by either calcium carbonate or calcium hydro-silicate, or mixture of both. Sand brick, with calcium carbonate as the cementing material, or "filler" of the spaces between the particles of sand, have been manufactured for fifty years or more. Sand brick with calcium silicate as the cementing, bonding and filling material, does not date back more than ten or twenty years. In the latter case, there is a chemical combination or reaction between the two constituents forming the brick, which binds the two together in a manner akin to vitrification. The resultant product is similar in many respects to dry press brick, in that vitrification does not penetrate to the core of each particle. In the former this is not the case.

For either product the necessary raw materials are the same—sand or a granular silicate and lime, (either a high calcium lime or a dolomite lime). The method of treatment during the process of manufacture differentiates them into three distinct products, all of which go indiscriminately under the same name.

SAND BRICK WITH EXCLUSIVELY CARBONATE FILLER.

It is obvious that the stone which has carbonate of calcium as a filler or binding material cannot have the same strength as the one in which there is a chemical union of the sand and the calcium or magnesium compound, as the case may be. However, the former can be manufactured at a less cost, and probably fills certain requirements in building construction. Therefore, we will give it brief consideration.

Twenty to forty percent of completely slaked lime is thoroughly mixed with sand and sufficient water to make moulding possible at moderate pressures. The hardening process is carried out in one of three ways:

First. The brick are exposed to the action of the atmosphere for a long time, the caustic lime thus slowly acquiring the needed carbon dioxide ($CaO + CO_2 = CaCO_3$). The necessity for complete slaking is evident, since any unslaked lime would slake in the air and rupture the brick. The time required before they can be used is five to six months, and they attain their maximum strength in about one and one-half years. The hardening here is similar to that of mortar, and like mortar is only superficial. The best lime for this purpose would naturally be a hydraulic lime. Zwick has said that only thirty per cent. of the lime in very old mortars, had been converted into the carbonate.

Second. Hardening in an atmosphere, rich in (CO_2) carbon dioxide, without pressure. This gives the same results as the first process, in less time.

Third. Hardening with (CO_2) carbon dioxide under pressure. It is claimed by some that this means gives a product in which nearly, if not all the calcium hydroxide $Ca(OH)_2$ is converted into carbonate. However, I do not believe that this has been satisfactorily proven.

SAND BRICK WITH PARTLY CARBONATE AND PARTLY SILICATE FILLER.

In this process the treatment up to the hardening process is essentially the same as just described, but the hardening is effected in a warm, moist atmosphere, saturated with CO_2

from the lime kilns, and the heat of slacking lime is used to aid in keeping the temperature up to 60–70 degrees C. A combination of the methods for class 2 and 3, provides for the introduction of CO_2 into the kettles or closed iron cylinders used for hardening in class 3. Under the conditions first cited, the product has a binding material for the most part $CaCO_3$, but some hydrated calcium silicate is probably formed, thus strengthening the bond. In the latter, the binding material in mainly the calcium hydrosilicate, and the amount of calcium carbonate much less than the former.

I am inclined to the belief that here also the superficial hardening prevents anything like a nearly complete change of the $Ca(OH)_2$ in the center of the stone. This of course would be no detriment to this product, or the preceding one, except to give a weaker brick, *provided only* that the surface had reached sufficient hardness and density to prevent all access of water or gases. If this is not obtained, we should expect effloresence as a result of the solubility of the calcium hydrate.

SAND BRICK WITH HYDROSILICATE FILLER.

This brings us to the third class, the only one which I think will ever take any important place in the world's markets. Therefore, we will go into the essential facts more closely.

The Sand.

The same raw materials are used as in class 1 and 2, viz. sand and lime. Considering the sand first, the following facts have been collected.

First. Almost any sand *can* be used, and a fair product produced, if the treatment is properly varied to suit the physical and chemical properties of the sand. Economy in manufacture, however, limits both physical and chemical properties.

Second. A comparatively pure sand is essential to cheap manufacture,—nor should the sand be too coarse. It is probable that for the best results most of it should pass through a screen, 20 meshes to the inch, unless there is a

good gradation from extremely fine to the coarse sizes, in which case perhaps coarser sand could be worked in to advantage. The product would not be as smooth and pleasing to the eye as one made from finer sand.

The object is to obtain a sand which will contain sufficient very fine particles to combine with the lime, and which when pressed will leave the smallest possible interstitial spaces, thus reducing the amount of lime necessary for welding these particles together.

Work done in connection with the cement industry has shown that practically none of the sand coarser than 100 mesh, and only a part of that of 150 mesh enters into the active cement reaction.

As an illustration, suppose we had one sand all of the size of walnuts, and another all of the size of wheat. Enough of the smaller could be mixed in to materially reduce the interstitial space, and yet leave sufficient space for a binding agent.

The finer the material, as a whole, the more difficult will it be to so mix it as to get a coating or film over each particle of sand. On the other hand, the union will be more complete, and the product more pleasing to the eye.

Experiments carried out by Prof. M. Gasenopp in the chemical technical laboratory of the Polytechnic Institute at Riga, the results of which were published in the Thon Industrie Zeitung for October 1900, Vol. 24, p. 1703 and Vol. 25, p. 762, clearly show the necessity of using fine sand for rapid and economic production.

The first set of results were obtained with fat lime as the active agent, and the second with dolomite lime.

In both cases a very pure sharp coarse sand 0.6 to 1.0 mm. in diameter was used, and a fine sand, 0.2 to 0.3 mm. in diameter. The fine sand was somewhat rounded and contained a considerable quantity of soluble silicic acid, therefore it was treated with HCl, and caustic soda solution, and washed before using in the experiments.

Each size of sand was treated with 10 percent and 20 percent of lime respectively, and with 10 and 20 percent of dolomite lime. High pressure steam was used. Both sets

were run for eight hours, one at 5 atmospheres pressure, the other at 10 atmospheres.

The tables of analyses of the resultant products given below speak for themselves. The soluble silicic acid is an index to the extent of the reactions. The methods of analysis are not given. The samples were exposed to the air for two to five weeks, which probably accounts for most of the CO_2 since the $Ca(OH)_2$ was not all converted into the silicate.

[See Tables I and II, pages 161 and 162.]

Considering the above table, we see that the coarse and fine sand was very differently affected under the same conditions, viz.:

TABLE III.

Percentage of Caustic Filler Used	Pressure of Steam in Atmospheres	Percentage of Soluble Silica found by Analysis of Product		
		Kind of Caustic Filler Used	Using Coarse Sand	Using Fine Sand
10	5	Pure Lime	0.43	3.06
		Dolomite	0.75	1.98
	10	Pure Lime	3 33	7.58
		Dolomite	3.14	6.29
20	5	Pure Lime	0.59	3.41
		Dolomite	0.65	....
	10	Pure Lime	2.75	11.14
		Dolomite	1.69	7.03

In every case the reaction is much more complete with the fine sand. This shows clearly the necessity for some fine quartz. The reaction has gone a great deal farther with the fine than the coarse, although the fine sand was not in as favorable physical shape for chemical union as the coarse. If soluble silicic acid were naturally in the sand, it might take the place of fine sand. In each case, the lime was not all combined with SiO_2, that is the reaction was incomplete, as is shown by the presence of uncombined $Ca(OH)_2$. After

TABLE I.

Series A. Brickettes in which pure lime was used. Analyzed after eight hours exposure in steam cylinder.

No.	Mixture	Stean Pressure in Atmosph're	Total CaO	$Ca(OH)_2$ from Total	MgO	Al_2O_3+Fe_2O_3	CO_2	Chemically Combined Water	Soluble SiO_2	Sand	Total
1	90 parts coarse sand..... 10 " lime.....	5	6.50	1.67	....	....	3.45	0.88	0.43	89.10	100.37
2	Same as No. 1.....	10	9.38	1.24	....	0.42	2.54	2.96	3.33	82.00	100.63
3	80 parts coarse sand..... 20 " lime.....	5	16.69	7.16	....	....	4.77	2.78	0.59	74.67	99.50
4	Same as No. 3.....	10	16.59	6.05	...	0.29	3.02	4.60	2.75	72.85	100.10
5	90 parts fine sand..... 10 " lime.....	5	8.74	0.85	....	0.31	3.75	1.79	3.06	82.02	99.67
6	Same as No. 5.....	10	10.10	0.58	....	0.56	2.23	2.55	7.58	76.38	99.40
7	80 parts fine sand..... 20 " lime.....	5	15.81	4.23	....	0.31	5.21	3.90	3.41	70.68	99.32
8	Same as No. 7.....	10	17.67	0.98	....	0.65	3.13	3.59	11.14	63.05	99.42

TABLE II.

Series B. Brickettes in which dolomite lime was used. Analyzed after eight hours exposure in steam cylinder.

No.	Mixture	Steam Pressure in Atmosph're	Total CaO	$Ca(OH)_2$ from Total	MgO	Al_2O_3+Fe_2O_3	CO_2	Chemically Combined Water	Soluble SiO_2	Sand	Total
1	90 parts coarse sand..... 10 " dolomite..... ...	5	4.98	0.38	3.81	0.23	2.21	2.24	0.75	85.23	99.45
2	Same as No. 1.....	10	4.49	0.43	3.45	0.96	2.05	2.13	3.14	83.61	99.83
3	80 parts coarse sand..... 20 " dolomite.....	5	8.56	2.53	6.58	0.70	3.38	3.44	0.65	75.80	99.11
4	Same as No. 3.....	10	9.97	1.92	7.57	0.95	3.19	4.39	1.69	72.62	100.18
5	90 parts fine sand .... 10 " dolomite.....	5	4.97	0.92	3.75	0.68	2.22	1.82	1.98	84.23	99.65
6	Same as No. 5.....	10	5.40	0.40	4.07	0.95	1.92	1.88	6.29	79.28	99.79
7	80 parts fine sand..... 10 " dolomite....	10	9.23	0.79	7.00	0.94	1.82	5.74	7.03	67.88	99.64

taking from the chemically combined water that which would go with the $Ca(OH)_2$, the balance of the water gives some striking molecular ratios to the soluble silicic acid. Thus from Table I we have

TABLE IV.

Series A.

Number	1	2	3	4	5	6	7	8
Ratio	3.7	2.66	6.50	3.7	1.7	1.	2.8	1.

Series B.

Number	1	2	3	4	5	6	7	....
Ratio	9.55	2.16	14.4	7.4	2.7	0.93	2.60	....

The ratios 6.5, 7.4, 9.55 and 14.4 seem a little unusual to me. It is notable, however, that with one exception, the high ratios are with the MgO.

These results also show clearly that high pressure is essential to anything like rapid working.

Professor Michaelis is quoted as saying the higher the pressure, the higher the soluble silicic acid, and the solider and denser the resultant brick.

Professor Michaelis has given the physical properties of the sand primary importance, and chemical properties a secondary place. He also says that two-thirds coarse and one-third fine sand give a denser and firmer brick than where the sand is all of one size. 70 per cent. coarse sand, 30 per cent. fine sand, with 5 per cent. added lime gives a good product, having 7 to 8 per cent. porosity. He has also shown that good brick can be made with sand carrying as much as 40 per cent. clay, if sufficient lime is used.

Judging from his figures, I should say for each part of clay present a little less than one part of lime must be added in excess of that which would be needed for the sand itself. While 2 to 3 per cent. of lime is probably all that is necessary to effect a satisfactory bond, in practice more is used, in order to hold the sand together and to facilitate pressing into a form which can be handled.

In conversation with Mr. H. E. Brown, of Coldwater, Michigan, recently, he said 2½ per cent. of kaolin added to a mixture of dolomite lime and sand had given him tensile strength higher, if anything, than brickettes made from same material without the kaolin. On the contrary, it is claimed by others that the clay has a tendency to reduce the hardness, and make the brick more susceptible to weathering action.

From theoretical considerations we might say the presence of silicates in any large quantity would act as a dilutant or inert material with perhaps a few exceptions. Kaolin (Al_2O_3, 2 SiO_2, 2 H_2O) may be converted into anorthite (CaO, Al_2O_3, 2 SiO_2). But we do not know this to be the case. Also anorthite, if present in the sand might take on four molecules more of SiO_2 and five molecules of H_2O as water of hydration and form heulanite (5 H_2O, CaO Al_2O_3, 6 SiO_2), and the acid orthosilicates represented by phenite (H_2O, 2 CaO, Al_2O_3, 3 SiO_2) might take on a molecule of CaO and give up a molecule of H_2O.

It is hardly likely that the normal silicates would become more basic in the presence of large quantities of available silicic acid. It is not likely that the metasilicates, represented by the simplest silicates of calcium and magnesium, enstatite (MgO, SiO_2) and wollastonite (CaO, SiO_2), can do more than promote crystallization of the calcium or magnesium silicates formed, by their mere presence in crystal form.

The silicates containing the alkalies, potassium and sodium, are probably barred on account of yielding soluble salts. From silicates of the heavy metals, the oxides would be thrown out. At any rate, they are too valuable for other purposes to be considered here.

Since under the working conditions, the very resistant quartz is brought into the reaction, the greater part of the complex silicates are very likely to be broken up into more simple forms, in most cases at least yielding inert compounds in part.

At any rate it is evident that when silicates are present in any quantity, more lime will be required, and while it might be possible to make a good brick from a silicate sand, it would not be a good business proposition.

As an instance of the weakening action of inert materials, we might cite the slightly lower crushing strengths as shown in a table given later.* Mr. H. E. Brown also confirmed this observation, finding the tensile strengths less on colored brick than on the same brick without the coloring matter, when treated in exactly the same manner.

Hence it follows that the sand should be comparatively pure, made up of medium coarse with some very fine grains. Sharp sand is preferable so as to present thin sharp corners to promote chemical combination. The sharp sand will also resist change of position or flow of solid particles better than rounded grains. If the sand available contained any large amount of clay it would probably be economy to roughly wash it. And if it did not contain sufficient very fine particles, a portion would have to be ground. This would increase the cost about five to seven cents per 1000 brick produced.

The Lime.

The prime requirement is proper burning. Since dead burning of limestone or dolomite tends to produce a crystalline oxide, which slakes or hydrates with extreme slowness, a portion might remain unslaked and uncombined, and make trouble by future slaking, and possible change of volume and possibly effloresence. It would hardly rupture the brick, since the crystalline oxide is said to hydrate without much change in volume.

Economy, however, indicates the use of the purer limes (lime, dolomitic lime or dolomite lime). The impurity is usually clay or sand, and at the temperature at which limes are burned, the SiO_2 will be combined with the lime, and the Al_2O_3 remain as such, both acting as inert bodies so far as sand brick are concerned.

German practice up to the present time seems to be to use only the fat limes. Ernst Stöffler, an engineer of Zürich, Switzerland, who has published a pamphlet on this industry, says fat limes are the best. Prof. Glasenapps' work, early in 1901, has shown that essentially the same results obtain when working with dolomite lime as with the fat limes.† I see no reason why dolomite lime should not be

*See Table VI. †See Table I.

a desirable material, except that it will require more care and time to properly slake it. We would have the increased fluxing action due to two bases instead of one. Even if the over-burning, which the MgO is bound to suffer before the CaO can be properly burned in a dolomite, should cause it to slake so slowly as to go through the process unchanged, it does not offer the same disadvantages that unslaked CaO would, since the oxide requires 1000 times its weight of water for solution, and the hydrate is practically insoluble. However the unslaked MgO would probably slake when exposed to the hot steam, and in that event might expand and rupture the brick in the hardening cylinder.

The dolomite lime may, however, give a brick which will be slightly lower in fire resisting quality than one made from the fat limes, especially if the amount of lime used is high. If this should be the case, it would not be due to the lower melting point of $MgSiO_3$ but, to the greater activity of two bases acting in unison on an acid.

PROCESSES OF MANUFACTURE PRIOR TO HARDENING.

Present practice adopts one of four methods prior to hardening: 1st. The wet slaking process. 2nd. The dry slaking process. 3rd. The acid slaking process. 4th. The quick lime or oxide process.

First Method.

This process consists in slaking the lime to a fat putty, either by hand or by mechanical aids, and then mixing in the desired proportion of sand and water, either in a wet pan or a large, slow moving pug mill. From here it is carried to bins over the press, allowed to stand a short time to ripen and then pressed.

With properly burned fat limes, the proper amount of water and sufficient agitation, this is accomplished very quickly and thoroughly. The heat given up by the union of CaO and H_2O is sufficient to generate steam in the minute pores of the amorphous oxide, and thus break it up into the smallest possible particles, constantly and rapidly exposing new and fresh surfaces to the hot water. CaO on hydration

gives up 270 heat units. Under these conditions the CaO seems to form a hydrate, carrying more than one molecule of water, the excess being locked in so loosely that a little excess of heat, as would be the case with too little water, would prevent its formation, or break it up if formed. Water acts as an equalizer; not enough allows it to get too hot, and too much cools it too low for the best results.

Walters found that the best slaking of high calcium lime gave an increase of volume of 3½, air slaking 2½, and slaking with a large quantity of water $1\frac{7}{10}$. This increase in volume gives it greater spreading or enveloping power.

With the dolomites more time is required for proper slaking, for two reasons: The MgO is somewhat over-burned, and second, the heat units evolved by MgO on hydration is much less than that for the hydration of CaO. Both act in the direction of retardation.

The process can be much improved and quickened by the use of hot water or the application of external heat.

It is claimed by many that the magnesian limes never develop the same degree of plasticity as the fat limes. This may in part be due to imperfect slaking.

Second Method.

This differs from the preceding only in this, that the lime is slaked with just enough water so that the heat of the chemical reaction shall just dry the finished hydrate. The hydration is incomplete in most cases. There are a number of patent machines for doing this, both in this country and in Europe. Some are closed tight, and the slaking done under pressure with water alone, others are treated with both water and steam.

In another type, water is added to the lime in a closed vessel, and heat applied externally by means of a steam jacket to the container.

Such hydrates of this class as I have examined, have been found to be very imperfectly hydrated. However, none were examined when water was added and steam supplied to keep the mixture hot, or where external heat was used.

Mr. H. E. Brown claims that dolomite lime hydrated under the conditions last mentioned in a steam jacketed

machine, showed on chemical analysis complete hydration, with a three-fold increase in volume, and yet a dry product.

Third Method.

Five to ten per cent. of a solution of commercial hydrochloric acid—19 degrees B., is added to the lime after slaking has begun. This is the German patent of Peter Kleber. (No. 103777.) This acid is worth about one to one and one-half cents per pound. In this process the preliminary treatment only carries the hydration to from one-third to one-fifth of completion.

This of course gives a small amount of $CaCl_2$. The affinity of this compound for water is well known. It is also very active in attacking silicates, as is illustrated by its action in the nascent condition in the J. Lawrence Smith fusion for the determination of alkalies.

The introduction of the acid must be objectionable at any rate, since if the $CaCl_2$ remains as such, it would be soluble later, and give trouble. If it is decomposed, and $Ca\ SiO_3$ formed, the acid liberated in the warm moist atmosphere must certainly attack the metal cylinders unless it is glazed with a silicate of some sort or lead lined.

$$CaCl_2+SiO_2+H_2O=Ca\ SiO_3+2\ HCl.$$

It is claimed by Kleber, that the HCl accelerates the slaking and shortens the time needed in the hardening vessel. The introduction of $CaCl_2$ is not so satisfactory as the use of the acid. While there are a number of plants operating under this patent, I do not believe that much acid is now used.

Fourth Method.

The quick lime or dry oxide of calcuim is mixed with the sand, and just enough water to make it possible to work it in the press. The water is added in two portions, with a short interval of time between additions. The product then goes to the press.

This certainly is the most rational and rapid method, if as good a product can be produced as by other processes. This process probably requires a little more lime than the others in order to get the mixture in proper condition to

mold. Where the cost of lime is very high, this would be an item. But much may be done to reduce this lime by mixing with it a portion of extremely fine ground sand.

If lime hydrates with steam under pressure in a crystalline form without change of volume, as Walter's experiment in hydrating lime in a glass tube with steam seems to show, the hydration during hardening would not in any way injure the brick.

Statements made to me by Mr. Brown, however, indicate that for dolomite there is a large increase in volume. He used water and steam both. My own experience points to the fact that both CaO and MgO will expand when treated with steam. If such be the case the fourth method would not be feasible.

It is also possible that the hydro-silicate of calcium may form direct from the CaO without change in volume. If this were the case, we should work with as little water as possible to get the denser brick.

HARDENING PROCESSES.

The hardening is accomplished in one of two ways, either by low pressure steam and long exposures, or high pressure steam and short exposures. In the first case, the pressure used is about two atmospheres, giving a temperature of 120 to 125 degrees C, and the duration of the exposure is about seventy-two hours; in the second case, the steam pressure is from eight to ten atmospheres, giving temperatures around 185 degrees C, and the exposure lasts for a few hours only, six to ten hours being sufficient in most cases.

The letters patent on this latter and most important procedure were taken out by Professor Michaelis early in the eighties, and permitted by him to lapse without commercial application.

I have already mentioned a modification of the hardening process in connection with class No. 2, in which CO_2 is introduced either with the steam or after it. If this method is used at all, it is usually when working with low pressure steam.

According to Stöffler, the quantity of lime used in any of the methods varies from 5 to 10 per cent. And the moisture above that used in hydration, from 7 to 9 per cent. The nature or the make up of the sand, whether quartz or feldspathic or clayey, will determine the amount of both lime and water desirable.

From the foregoing statements you can readily conceive that it would be entirely feasible to take the sand from the bank and have a brick ready for market in less than a day of twenty-four hours, or if you include the burning of the lime, the entire process from the raw limestone and sand to the finished product need not consume more than thirty-six hours.

QUALITY OF THE PRODUCT.

Concerning the quality of this new artificial stone, the question arises in the mind of each of us: "Is it of any value to us?" "Will it fulfill our requirements for a safe and desirable building material?" I think it will, and offer the following as evidence of its quality:

The sample before you is one made in Germany, by the Stahl and Eisen Actien-Gesellschaft, Hoerde, Germany, from materials which you will see were not the most desirable. An analysis by rapid methods gave;

84 per cent. SiO_2 (sand and Sol. SiO_2).
2 " $Fe_2O_3+Al_2O_3$
7 " CaO
" MgO low.

93. per cent.
7. " Balance is made up of MgO, H_2O and CO_2 and Alkalies.

When three grams were ground fine and treated with a large amount of water, only a trace of Ca was found in the water.

The water absorbed on standing over night is 9 per cent. The question naturally is, "Will it stand weather?" The small piece was soaked in water, frozen and thawed three times. It was thawed out the last time on the laboratory hot plate at about 250 degrees C. I could observe no

evidence of damage by frost, except when it froze fast to a sandstone window-sill, and broke out a little when I wrenched it loose. After thawing out, and while still wet, I set it up and turned a blast lamp directly onto one small piece of it, and brought it up rapidly to a bright red heat, and held it for fifteen minutes, then plunged it into cold water. This last proceedure destroyed the bond, as you can see by rubbing the brown spot on the brick. A block sawed from this brick and crushed, showed a crushing strength of 4210 pounds to the square inch.

Further in a paper given by Herr G. Beil, of Aschersleben, at a meeting of the Kalksandstein society in Berlin, March, 1901, the following results are given as coming from The Köenigl. Mechan–technichen Versuchsanstalt, at Charlottenburg, Germany.

Seventy brick, representing 7 different products, were soaked in water at 12°-15° C., frozen for four hours then placed in warm water three hours. All were pronounced sound at the end.

Also the following list of tabulated results (published in Vol. 25 Thon-Ind. Zeit. 575):

TABLE V.

Number of Test		Absorption	Crushing Strength, in pounds per square-inch		
		Amount of water taken up by dried sample, after 125 hrs. soak, in percents of dry weight.	Water soaked Brick	Dry Brick	After Freezing
1	High Pressure Hardening	12	1903	1704	2229
2		14	2073	2215	2300
3		9	3933	4189	4260
4		10.6	1846	1732	2187
5		——	——	3710	3238
6	Low Pressure Hardening	——	——	850	1335
6a		——	——	1353	1747
7		18.3	1335	1193	1562

This shows that the crushing strength is not, in most cases, very materially decreased by freezing. Crushing wet also produces a slight decrease.

In the Thon-Ind. Zeit. Vol. 25, 1660, the following tabulated results are to be found:

Swedish brick, tested at Gothenberg by same method as in above Table V.

TABLE VI.

Kind of Brick (All Lime-Sand)	Specific Gravity in Powder Form	Actual Specific Gravity	Percentage Absorption	Porosity in Percents of Volume	Number of Brick Tested
1. Smooth, gray-white	2.51	1.74	13.1	30.5	10
2. Yellow-brown to red	2.46	2.10	13.6	14.6	10
3. Smooth, gray-white	—	—	—	—	4
4. Brown-red	—	—	—	—	4

	CRUSHING STRENGTH								
	Dry			Wet			Frozen Repeatedly		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
1. Same as above	17.32	12.21	15.48	15.90	10.37	13.21	14.91	7.24	11.93
2. Same as above	14.63	7.53	11.08	14.48	6.36	9.80	11 64	9.23	10.08
3. Same as above	27.41	15.19	22.86						
4. Same as above	21.58	12.35	15.62						

I do not know the process of manufacture.

This again shows a slight decrease in crushing strength after repeated freezing.

Mr. Brown has obtained tensile strengths as high as 650 pounds, but gives as an approximate average for ten per cent. of the hydrates 400 to 425 pounds. He thinks the maximum tensile strength is obtained with very fine sand and about fifteen to twenty per cent. of the hydrated dolomite lime equivalent to nine to thirteen per cent. of the oxides.

A cube 2x2x2 made by Mr. Brown from finely ground sand and dolomite lime, gave a crushing strength of 5730 pounds to the square inch when crushed in the mechanical laboratories at Ohio State University.

The following is a copy of tests made on brick manufactured by H. Huennekes:

Tests of Lime—Sand Building Brick.

Made for A. G. Roenick, 408 Wood Street, Pittsburgh, Pa., by the Pittsburgh Testing Laboratory, October 17, 1901:

Crushing Strength Per Square Inch	Absorption Test 45 Hrs. in Water.	Absorption After Freezing Test	Crushing Strength Per Square Inch After Freezing
3518 lbs.	11.6 % gain	12.4 % gain	*4137 lbs.
4162 lbs.	8.57 % gain	8.8 % gain	*5202 lbs.
3859 lbs.	11.3 % gain	11.4 % gain	

*Bricks did not crush at this load, but showed only slight cracks at an actual load of 105,000 pounds, the limit of the machine.

Half bricks were used in absorption tests; these bricks were dried thoroughly before immersing in water. After remaining in water forty-five hours, bricks were frozen four hours at a temperature of 14° Fahr., and then thawed in warm water twelve hours, frozen again at a temperature of 9° Fahr. for a period of three and one-third hour, thawed in hot water three hours, frozen at a temperature of 12° Fahr. for three and one third hours, and finally thawed in hot water for twelve hours. Final absorption test made and then bricks were again thoroughly dried. The bricks showed no signs of cracking or disintegration.

From the foregoing, it is evident that any of the high pressure steam process stones have strength to meet all ordinary requirements for building purposes. In Germany a great many of the fire inspectors have pronounced them a safe material from their standpoint, and a good many sand-brick have gone into municipal and government buildings over there. The railroads are using them also.

I have taken the following from Thon-Ind. Zeit. V. 25, 1822:

A small oven was built of brick made by high pressure steam hardening, by Guthemann, of Niederlehme, some whole and some bats. It was fired by wood up to a temperature of 1100 degrees C, measured both by Seger cones and

by electric pyrometer. The stones were not injured in any way by this process, and further showed that they were excellent non-conductors of heat.

Later, by means of a blast, the furnace was brought to a glowing heat and the hose turned directly on to the hottest part with a full stream. This cracked off a few corners. When thoroughly cooled it was found that the bond had been destroyed for a depth of 3 cm.= ¾ in., so that part could be scraped off with a knife.

Mr. G. Beil, Thon-Ind. Zeit, 25, 577, cites the following good qualities:

1. Great hardness.

2 and 3. Regularity of form which permits of more rapid and consequently cheaper building.

4. The beauty of the structure.
5. Outside dressing or painting unnecessary.
6. Inside plastering unnecessary in many cases.
7. No insulation necessary.
8. It is cheaper than cut stone or terra-cotta.
9. Cheaper than brick. The costs in Berlin are: Ten to twenty marks per 1000, for sand-lime brick; seventeen to twenty-five marks, per 1000, for face brick. Of course eight and nine represent German conditions, not American ones.

MECHANICAL EQUIPMENT FOR MANUFACTURE.

As has been intimated in previous statements, the machinery in a general way consists of apparatus for either wet or dry slaking, conveying machinery, mixing machines, presses, trucks, hardening boilers and machinery for generating power.

There are a large number of patented machines for the dry slaking of lime, both in this country and in Europe. I know of but one, however, for wet slaking. In this latter process, the lime is slaked with sufficient water to make a good putty, and after maturing in this condition, it is dried by artificial heat and ground.

Since in the various patented processes for making sand brick, the only claim which, in most cases, could be con-

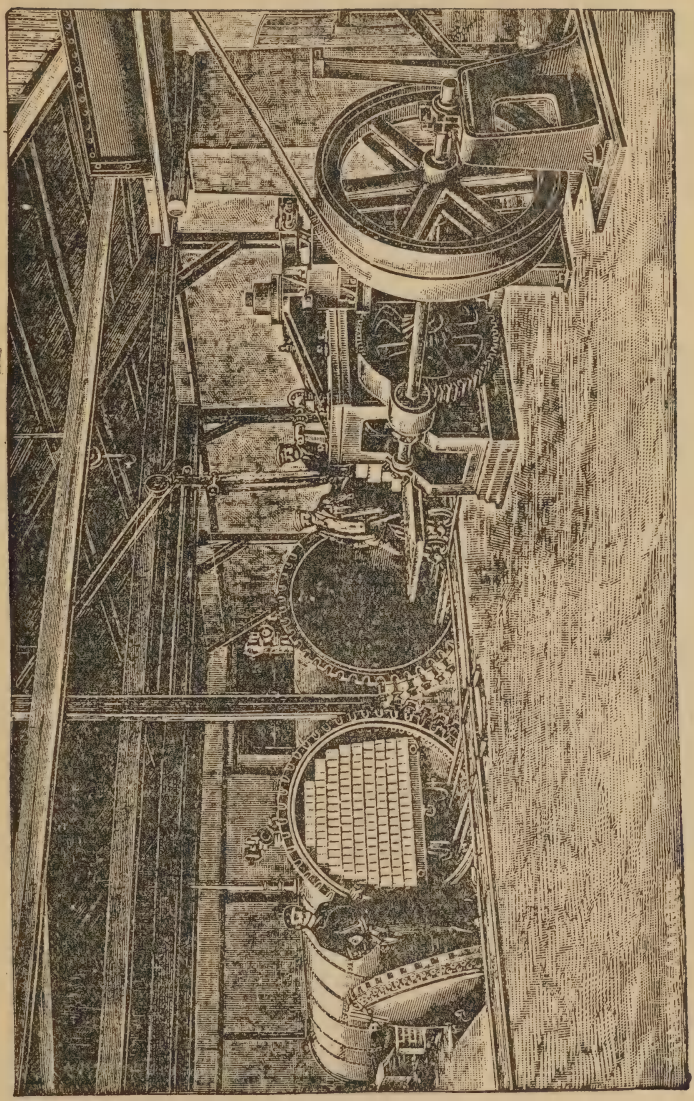


Figure I.

tested, is that for some special machine or method of slaking lime to a dry powder. I will briefly mention a few of them:

Olschewsky, in one of his German patents, uses a cylinder capable of resisting strong pressure, so mounted that it can be rotated, and receive a supply of water at the same time. The cylinder is filled one-half full of CaO, and sealed up. Rotation and the introduction of water begins: rotates one-fourth to one hour, and allows to stand two or three hours. Thirty to thirty-five parts of water are used to one hundred parts of lime.

From what I have seen in this country, I feel safe in saying such a machine will give imperfect hydration.

Another of Olschewsky's patents, German No. 82785, consists in the the building of a tight metal box in the bottom of the trucks for carrying the brick in the hardening chamber. This is provided with a stirrer, a shaft with peddles. Water and steam are introduced. The heat generated serves to dry the green brick. This wagon then is run into the hardening chamber, and you always have one day's supply of slaked lime ahead.

The German patent, No. 82785, was recently annulled.

This device or proceedure is patented in England, 1900, No. 1705, and in the United States, Dec. 1900, No. 663459.*

There are several other American patents using various forms of agitators.

Another we might mention is that of A. G. Schwarz, of Zürich, Switzerland, in which the machine is heated by steam pipes and the hydrate is dried by producing a vacuum, as all excess of water is pumped out as vapor. This machine is illustrated and described in "Silico-Calcareous Sandstones," by Ernst Stöffler.

Mr. H. E. Brown holds patents which claim for dolomite lime everything which is claimed by the Germans for lime.

It is apparent that the best conveying machines will be those which will move the material with as little friction between the conveyor and sand as possible, on account of the latter's strong abrasive properties. Broad continuous

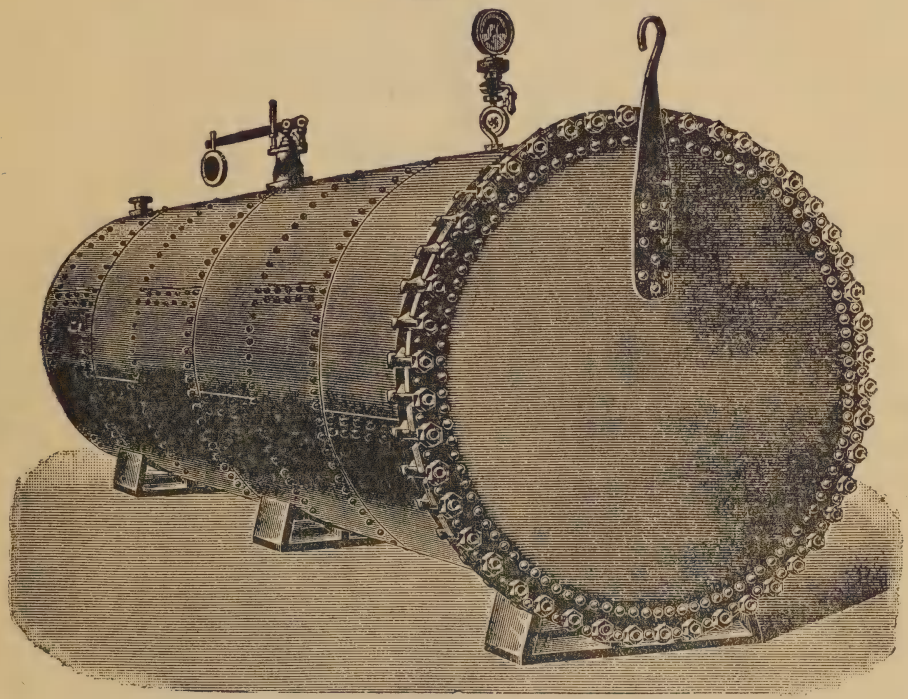
*See Patent Office Gazette, Dec., 1900, page 1946.

belts, where feasible, or heavy chain bucket conveyors are perhaps best adapted to this purpose, where dump cars are not desirable.

If screws or auger machines are used for conveying or mixing, they should be of large diameter and capacity, and geared to move slowly.

Edge runners are much used in mixing and grinding.

Figure 11.



The trucks are usually built low and made to carry from 1,000 to 1,400 of brick of American size, or fewer of German size. They usually carry thirteen to sixteen courses.

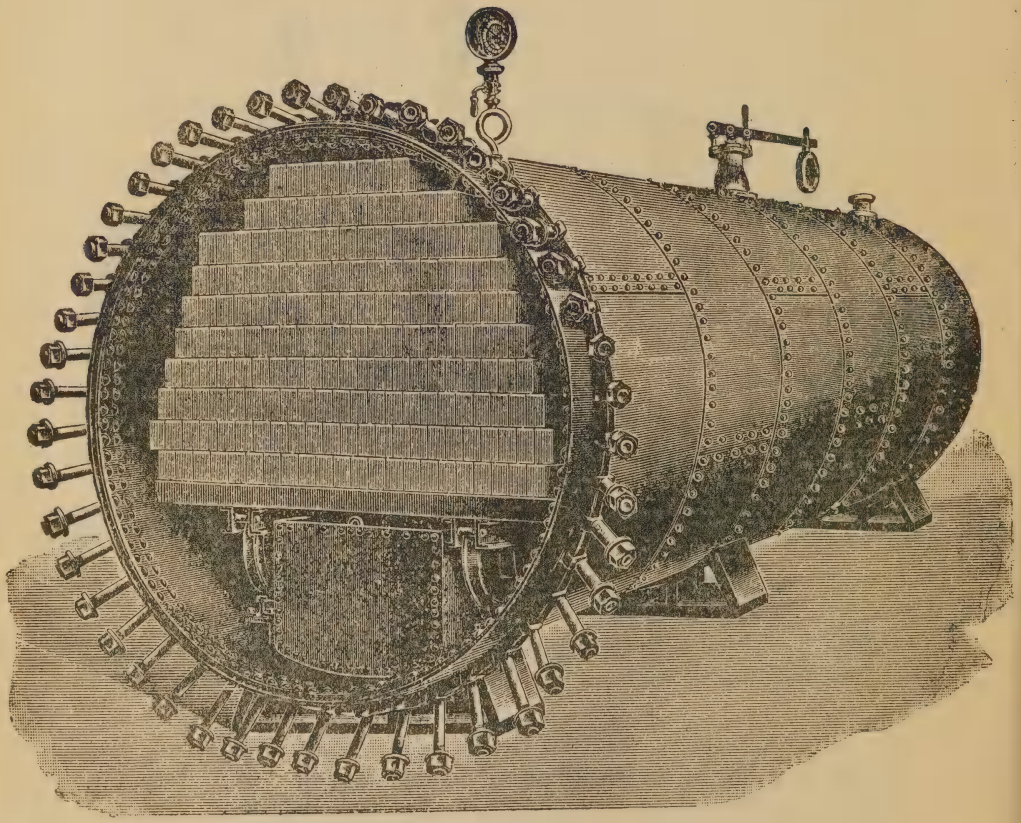
The hardening boilers are made of iron or steel, and constructed to stand for high pressure — 150 to 200 pounds pressure to the square inch. They should always be bricked in to prevent rodiation and excessive condensation of steam. They usually have one head movable and bolted on. This head is handled by a small crane.

The customary size is six to seven feet in diameter by fifty to 60 feet in length.

Figure II shows a hardening boiler closed.

Figure III, a similar boiler open and charged ready for steam as soon as the head is bolted into place. This plate also shows a container for slaking lime, under the floor of the truck.

Figure III.



There are a number of mixing machines in use — wet pans, auger machines, pug mills, &c. One of rather unique type is that of A. G. Schwarz. It consists of a drum with a mixing arm. A cut of this machine may be seen in "Silico-Calcareous Sandstones." It is arranged so as to remove

moisture by producing a vacuum, and then add a definite amount of water, working on definite amount of material. It is necessarily intermittent in its action.

Although an expensive way of operating, it has some things in its favor, since the amount of water cannot vary widely for any given mixture. The amount of water which is best must be determined for each plant.

When once this is determined the Schwarz machine offers a means of always getting that amount into the material.

COST OF PLANTS AND PRODUCTION.

Ernst Stöffler, of Zürich, in his pamphlet gives the following for a plant using quick lime. The cost of a plant and of production will not vary widely from this for any of the others.

PLANT, 40,000 DAILY CAPACITY.

Land and Buildings.

	About 5000 m_2 of land, of which about 1500 m_2 is built over, machine masonry, chimney, tracks silos, etc....	$24300 00

Machinery Plant.

A.	Preparation of the lime: One stonebreaker, conveying screw with elevator, one ball-mill, tilting waggons.....	2332 80
B & B_1	Mixing machines: Two elevators, two intermittent-charge mixing machines, wagons, two continuous mixing machines, moistening apparatus, two elevators.....	4082 40
C.	Press room: Two endless belt conveyors, six mixing machines, six presses, wagons, moveable platform.....	14774 40
D.	Hardening room: Three hardening boilers with pipes.....	7776 00
E.	Boiler: Two steam boilers	5054 40
F.	Engine house: Steam engine.	2916 00
G.	Shafting and pulleys.....	2916 00
H.	Lighting.....	1166 40
I.	Unforseen, sundries.....	2721 60
		$68040 00

To bring the machinery to this country, excluding hardening room and power machinery, would cost an import duty of 45 per cent. of the German valuation; therefore, we have

A	$ 2,332.80
B	4,082.40
C	14,774.40
Total	$ 21,189.60

Duty = $9,535.03 — and freight and transfer charges will bring this up to $10,000, so we would have such a plant costing in this country about $78,000 equipped with German machinery. This alone would add eight cents per thousand to the cost of production.

Figures for cost of production B:

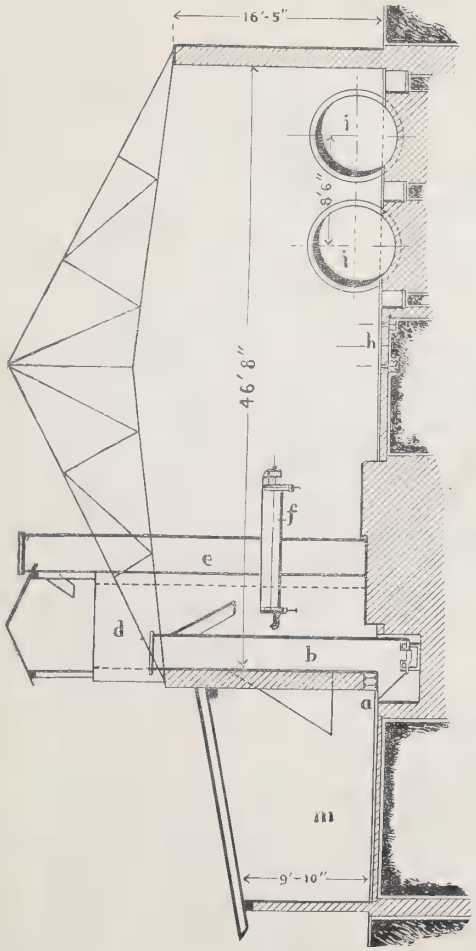
AMERICAN CONDITIONS OF PRODUCTION.

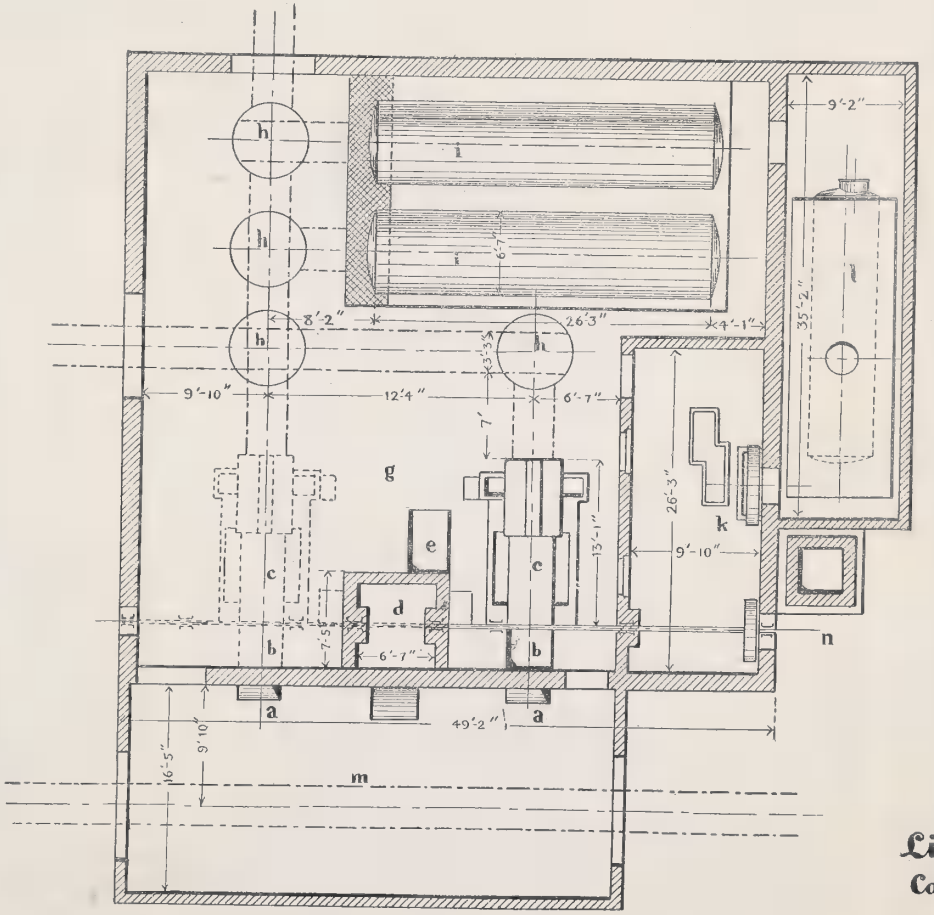
Sand — 157 cubic yards @ 7 cents	$ 11 00
Lime — 13 cubic yards = 11 tons @ 4.00 per ton — ($3.00 if you own your own stone and burn it yourself)	44 00
Coal — 3 tons @ 2.25	6 75
Repairs	5 00
Oils, etc.	3 00
Forty workmen @ 1.35	54 00
Foreman @ 2.50	2 50
Office expenses	20 00
Depreciation and interest, 10 %	20 00
	166 25
Selling expenses — about 10%	16 00
	182 25

According to the estimate, the brick could be put on the market without profit at 4.55 per 1,000 when machinery is bought in Germany and with a plant costing $80,000. However, there is no necessity of importing machinery.

A plant with American machinery will cost about, as follows:

A liberal estimate for land and buildings, I think, would fall well within	$15,000 00
One wet pan (30 HP)	1,000 00
One Ball mill (5 HP) or other arrangement	500 00
Two presses	4,400 00
Two pug mills (20 HP)	800 00
Conveying machinery	6,000 00
Shafting and belting	3,000 00

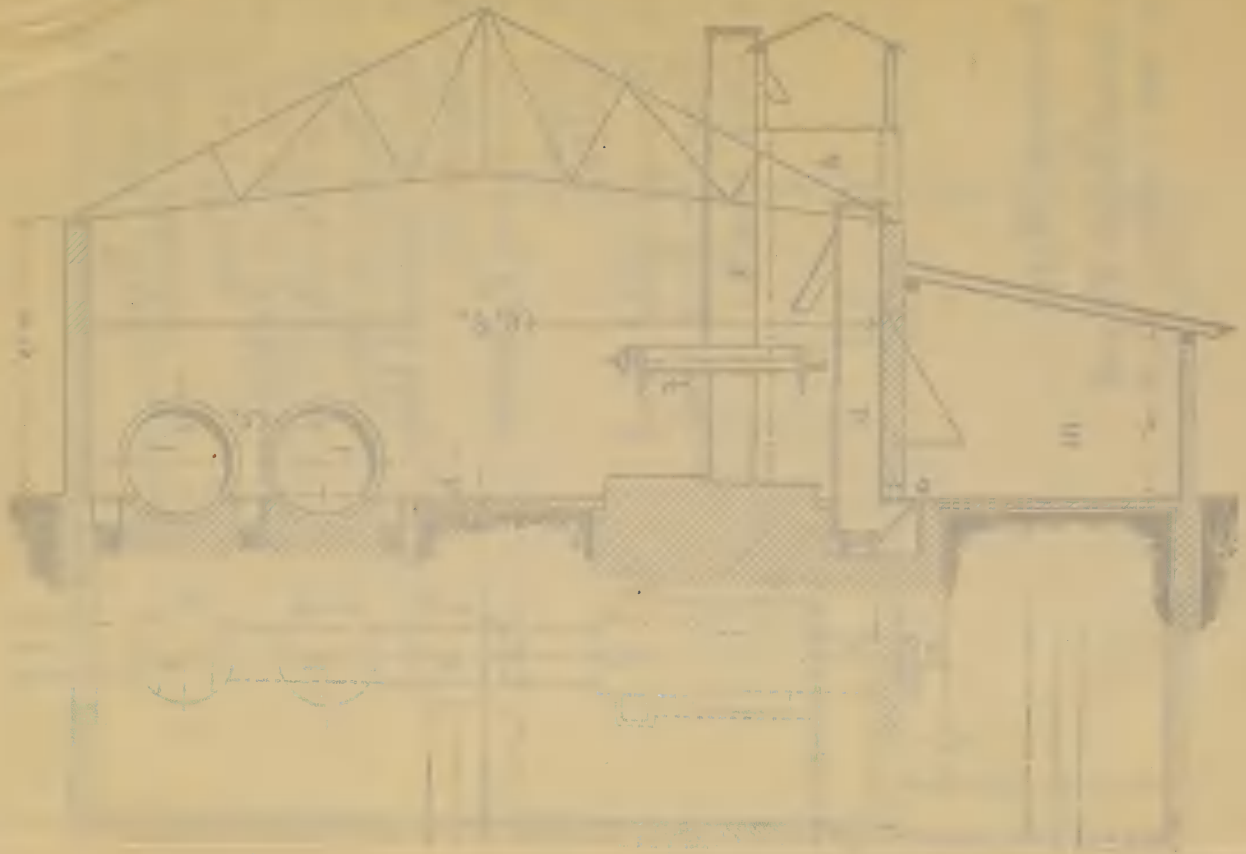




a Elevator Boot.
b Sand Elevator.
c Brick Press.
d Lime-silo & Pulverizer.
e Lime Elevator.
f Differential Mixer.
g Bin for slaked lime.
h Turntable.
i Hardening Cylinder.
k Engine.
l Boiler.
m Storage shed and Elevator feed room.
n Line shaft.

Ground Plan for Lime-Sand Brick Plant

Capacity 10000 to 20000 per day.



One 100-HP Corliss engine	2,500 00
Two 100-HP boilers	2,000 00
One 25-HP boiler	300 00
Four hardening boilers, 7 diameter by 60 long	8,000 00
Placing same and insulating same	1,000 00
Pipes for preliminary heating	1,000 00
Railroad tracks and unforeseen expenses	4,500 00
	$50,000 00

I think a plant satisfactory in every way could be installed for $50,000, and brick produced for $4.00 per M., ready for market, if the plant was favorably located.

At any rate, it is safe to say that this product can be put on the market as cheap as pressed brick, since the losses in manufacture, in a plant in good running order, do not exceed two per cent.

I have purposely made estimate of cost of plant rather high, since with any young industry there is more or less delay and expense in getting everything properly adjusted. The time consumed and amount of this expense of course will depend on the ability of the men in charge.

I have used the figures given by Mr. Stöffler since they seemed to represent about the average of several estimates which were available for comparison.

In the back of Mr. Stöffler's book, "Silico–Calcareous Sandstones," are a number of plates giving plans of various sand brick plants.

The plans here published were furnished by Mr. Fred C. Jenkins, of Hamburg, Germany.

The plan of plant here given is not one which would meet our requirements, but is given to show what sort of a place the sand brick plants now operating are. The illustrations were copied from advertising matter, because they show types now in use.

I take this opportunity to acknowledge my indebtedness to the following persons for much valuable information: Stahl and Eisen Actein Gesellshaft, Höerde, Germany; C. Luke, Eilemburg, Germany; Fred C. Jenkens, Hamburg, Germany; Ernst Stöffler, Zürich, Switzerland; Sandsteinziegelei-Patente Schwarz, A. G., Zürich, Switzerland; Brüch Kretschel & Co., Osnabruck, Germany.

One plant has been started in this country and two more are contemplated soon.

DISCUSSION.

The Chair: We have with us this morning, Mr. H. E. Brown, of Coldwater, Mich., a cement chemist, who is interested in the sand brick industry, and who has taken out patents, I believe, in connection with the same.

Mr. H. E. Brown: I have with me this morning, as you will see on the table, some results of investigation of the sand brick question, as carried out in the laboratory of the Michigan Portland Cement Company, and I will be glad to have you examine them. They were not made under ideal conditions, however, because all had to be done by hand methods, and these methods could not be just exactly the duplicate of those which would be carried on with machinery.

I will say in regard to Mr. Peppel's paper, and concerning cost of installation of a plant, that I think he has been very liberal in his estimates of cost of installation of plants. From some few figures which I have been able to obtain from builders of machines, I think that he has figured very liberally, and a person would have quite a good working capital left, if he had fifty thousand dollars in his pocket with which to build a plant to make 40,000 brick per day under my patents.

You will notice in the tensile tests of brickettes, mentioned in this paper, that they were as high as 600 pounds to the square inch. This is stronger than cement brickettes. Brickettes made of one part of cement and three of sand on a seven-day test, usually give 300 pounds per square inch; on twenty days' test, it usually runs up to 400, 450 or 500 pounds. A brick made from one part of dolomitic lime and nine parts of sand, thirty-six hours after being made, will, when submitted to tensile test, give about a uniform test of 400 to 450 pounds to the square inch. I will be pleased to answer any questions as to the details of the business, as far as I am able. My patents have not as yet been published, and I am now working to secure a better knowledge of the actual working conditions to be met and overcome.

BACTERIAL GROWTH AS A FACTOR IN AGEING CLAY MIXTURES.

BY

EDWARD C. STOVER, TRENTON, N. J.

The ageing of clay mixtures before use, has been practiced in the pottery industry so long, that even the histories of the art do not shed light on when it was first begun. It is quite likely that the benefits in "ageing" mixtures, like numerous other improvements, was first discovered accidentally, centuries ago; perchance, some sanguine clay worker had his fond hopes blasted by his inability to use some new mixture which he had put together with the hope of improving his wares, and after numerous fruitless efforts, was compelled to cast the whole batch aside, and return to his old mixtures. Months, and perhaps years may have elapsed, when a series of conditions arose which prevented him from getting his old supply of materials, and, driven by a pressing demand for his product, he, as a last resort, decided to make another effort with the old abandoned batch, and was astonished to find that it not only worked better and easier, but that he had less loss in drying and firing than ever before in his experience, and thus the discovery may have been made. It has been said that the ancient Chinese potters worked up the mixtures prepared by their forefathers, and and that they in turn put up and stored away the mixtures for the next generation.

Be this true or not, we all know from our own experience, that the proper ageing of clay body mixtures greatly increases plasticity, and lessens cracking in drying and firing, and the questions naturally arise: "What has taken place during this process of ageing, and what has caused this change in the mixture?" The answer to the first is apparent: When a mixture of the different materials is first made, certain affinities or attractions remain unsatisfied, so to speak; they are attracting or in search of other affinities, which, in turn, are also attracted towards them, but owing

to their location in the mixture they are unable to unite, and thus the batch is truly a mixture and not a compound. Proper ageing, however, results in a re-adjustment, as it were, and the searching affinities have found their mates and become satisfied, and the batch has become a compound.

What has caused the change, or made it possible for the mixture to become a compound, is the perplexing question. Having given this subject considerable thought, and after making numerous experiments, I find this change is a fermentation caused by bacterial growth. During the last few years, these infinitesimally small organism have engaged the attention of some of the most eminent scientists, and by their discoveries, particularly in the medical field, our knowledge of the world has been wonderfully modified and enlarged. Quite a number of species of bacteria have been found in water alone, while those found in clays and soils number hundreds.

To get anything like definite data on the subject in hand would require months of constant labor in bacteria culture, and the examination of all of our materials used, and the elimination and classification of the various groups, and the determination of the effects on each of nitrogen, hydrogen and the other common gases and elements generally, and how each class would thrive under different degrees of heat and cold, and how each class would change at different intervals of time, all of which would require more time and attention than could be given by a potter, with his time fully employed each day.

As is well known and established by the works of Pasteur, Koch, Cohn, Tyndall, and many others, fermentation is the result of bacterial growth. Like the investigation of almost any scientific point, that may seem a very small one, and obscure at first glance, this subject on investigation, looms up with innumerable phases, till one inexperienced in bacteriological work is at a loss to know where to begin.

In making examination, I was assisted by I. M. Shepherd, A. M., M. D., a graduate of the University of Pennsylvania, and A. W. Atkinson, A. B., M. D., a graduate of the

Hahnemann College, Philadelphia, Pa., both experienced in bacteriological work, and to both of whom I am indebted for much information and literature on the subject.

The predominating species found in clay mixture is believed to be bacillus sulphureum, also called proteus sulphureus; they give off sulphuretted hydrogen gas (H_2S). Their development is facilitated by a temperature of 37 degrees C, to 38 degrees C, which is equal to 98.6 degrees to 100.4 degrees F.

In a fresh mixture allowed to stand in the slip state, the fermentation will be completed in from six to twelve weeks, according to the temperature and other conditions, without inoculation, but by inoculation, the time is cut down to two to four weeks under the same conditions.

As the ageing of body mixtures is mostly done in damp cellars when clay is fresh from the presses, it could readily be thoroughly mixed and inoculated by pugging and adding at the top of the pug mill a small stream of well inoculated and seasoned slip of the same mixture. Then pack away in the damp cellar, and keep constantly warm and damp, but not moved. In this way the full benefits of a proper ageing could be accomplished in a very short space of time, the many economies of which are obvious.

DISCUSSION.

Mr. Stover: I want to say that Mr. Paul Gates has a microscope and some fine slides in his room, of which you can get some idea from the micro-photographs which I have passed around. Plate A. shows in the center a long snake-like bacterium about ready to break apart. Plate B. shows a number of very small parallelograms clustered together, evidently parts of a large one that has just separated. Plate C. shows a number of the small parallelograms scattered among the irregular dark marks. The former are bacteria, the latter are the particles of clay substance. Mr. Gates extends an invitation to all who may wish, to call at his room and see these little fellows in motion; and I must say that my own ideas were very much less clear until I saw what he has to show. I made several efforts to get some-

thing tangible to bring to this meeting, but did not succeed, and I feel credit is due to Mr. Gates for making this paper so much more real than it would otherwise be.

Mr. F. W. Walker: I am more and more impressed with the great modesty of our members, and those who have had the greatest experience are the most modest. This point touches the white-ware potter particularly. The brickmaker weathers his clay in the open air, under conditions which are not so favorable to the growth of bacteria. We sometimes think our cellars should be kept clean, but Mr. Stover has pointed out that to be useful, they should purposely be kept infected with bacterial growth all the time.

Mr. S. M. Ferguson: The ageing of clays is a big thing in reducing potters' losses. Some white ware potters mix from day to day, and have great losses; while others mix two months ahead, and thus reduce their losses wonderfully.

Mr. D. C. Thomas: Sometime ago our firm began using chemicals to wash our press cloths out. I was rather surprised, and asked why it was done. The reply was that there was something in the sacks that destroyed them. I commenced making inquiries, and learned that a chemist for some southern clay firm had reported that he had found bacteria in the clays. And that the bacteria were what was destroying the sacks. I began then to think that perhaps this question might have some bearing upon the ageing of clays. I had no proof, but I had my own opinion.

Mr. S. M. Ferguson: At one time, we had about twelve presses of slip, which were left in the agitator for about a month, owing to a sudden shut-down. When we started, we pumped it into the presses, and it destroyed a bran new set of sacks entirely. They were no good at all after pumping those twelve presses of slip. The sacks were practically gone. The only way we could account for it was from the ageing of the slip. It was blue when it came from the press, but it should been a white mixture. It was an excellent clay. The hands all said the body had been changed. I said it had not, but they insisted it had, for the clay was now blue, and smelled bad; in fact, the clay was practically

rotten. But in the evening of the first day, every person was telling me the results of the day's work. Every one said that they had better results, less cracking, &c., and the clay worked extra well. But it was hard on the press cloths.

Mr. John Stamm: We are of the same opinion as Mr. Ferguson. We always try to keep the cellar full of clay. The older it is the better, and the less loss we have. That is the way we find it.

Mr. Stover: There is one point I want to make — having been convinced that the little creature is there, we want to use him to the best advantage. We all know that if we get a six month's supply of clay ahead, and there is any mistake, it is a good deal of loss. But if we could accomplish the desired results by adding a well inoculated slip in the pug mill, and thus get the clay in the proper condition to promote the most rapid fermentation, I believe in two or three weeks' time we could get a body which would be as mellow and ripe, so to speak, as we now get in several months' time.

Mr. S. G. Burt: We have had this topic up for discussion sometime ago in the society. The idea, as Seger expresses it, is that as your clay stands in ageing, it gradually developes an acid. I do not think he went so far as to get to the point of bacterial growth. What he clearly claims, and I think proves, is that it is this development of acid which actually brings about plasticity. He gives examples of it by testing clay with a little sodium hydroxide in it, which would not settle for a long time, and when it did, was very weak or tender. He prepared another, I think, with acetic acid, which so increased the toughness of the clay as to make it stand working extra well.

If these animaculæ are going to produce sulphuretted hydrogen, they will have to draw the sulphur from the pyrites present. It does not throw any light on the acid formation. I don't know what organic acid they could create, or whether there is any direct connection between the formation of acid, and the bacteria; but Seger has shown that the formation of an organic acid is the direct cause of increased plasticity in the clay, which is a great benefit to the potter. Mr. Stover and Mr. Ferguson's contributions seem to connect this acid formation with bacterial life.

Mr. W. D. Gates: I hate to differ with my learned brothers on these matters. My impression was that we might cultivate this bacterial growth by changing the chemcal conditions, as much as by changing conditions of temperature—possibly more so. The experiments that we have conducted show that with alkaline conditions the bacterial growth in our slip was greatly increased; with acid conditions, bacterial growth was destroyed.

Another theory of mine is that the plasticity does not so much depend upon the acid condition, as upon a gelatinous secretion made by the bacteria in the slip. It seems to me that a wide study of this would be abundantly interesting. I think the most favorable conditions can be controlled, not only by atmospheric and heat conditions, but also by chemical conditions of acidity or alkalinity; and that by regulating these conditions, we can handle this fermentation much as we please. I think you will all be interested in looking at these microscopic exhibits. They are certainly open to you, and I think will come cheaper to you than they did to me, perhaps.

Mr. Stover: Just a word as to what Mr. Burt said as to acid conditions. Immediately on finding sulphuretted hydrogen, the question arose as to where we got the sulphur. Then came the question, couldn't we get the same results by adding a dilute solution of sulphuric acid. We took some fresh white mixture that had not been inoculated, sterilized it first, so as to be sure there would be nothing alive in it to start with, and added a diluted solution of sulphuric acid with the hopes of doing the same thing quicker. I thought if we could get the result this way in half an hour we could abandon the clay cellar. But I found it would not do it. But a small amount of the dark blue slip-mixture placed in some of this same sterilized material gave the full benefits of ageing in a very short space of time.

THE EQUIPMENT OF A MODERN PAVING BRICK PLANT.

BY

WILLARD D. RICHARDSON, CLEVELAND, O.

While the American Ceramic Society must be concerned chiefly with the higher branches of clay working in which there is a greater scope for science and art, yet, we who are permitted to enjoy membership, even though engaged in the more common and less skillful department of brick-making, expect some light to be shed upon the obscure and uncertain places in our path, some investigations to be made by the society, some facts to be brought out at these meetings that will result in more exact and definite knowledge of the processes we employ.

That noble man, that eminent ceramic technologist, Dr. Herman H. Seger, did not confine his investigations to the problems of the potter, but gave much of his time to the study of the processes of the brickmaker; and the results of his labors, which our society is about to make accessible to the clayworkers of America, are as valuable a contribution to us who are making the common and homely brick as to you who are making the beautiful and artistic pottery wares.

So we brickmakers are greatly benefitted by our connection with this society, though we can give little in return for what we receive. We pay our dues and attend these meetings and listen to the learned discussions of your scientific clayworkers, and absorb and assimilate what we can, and are stimulated to better, more progressive work and perhaps thereby be enabled to enlarge our sphere of action.

For my part, I would not presume to take up the time of this meeting with what I have to offer, but our secretary

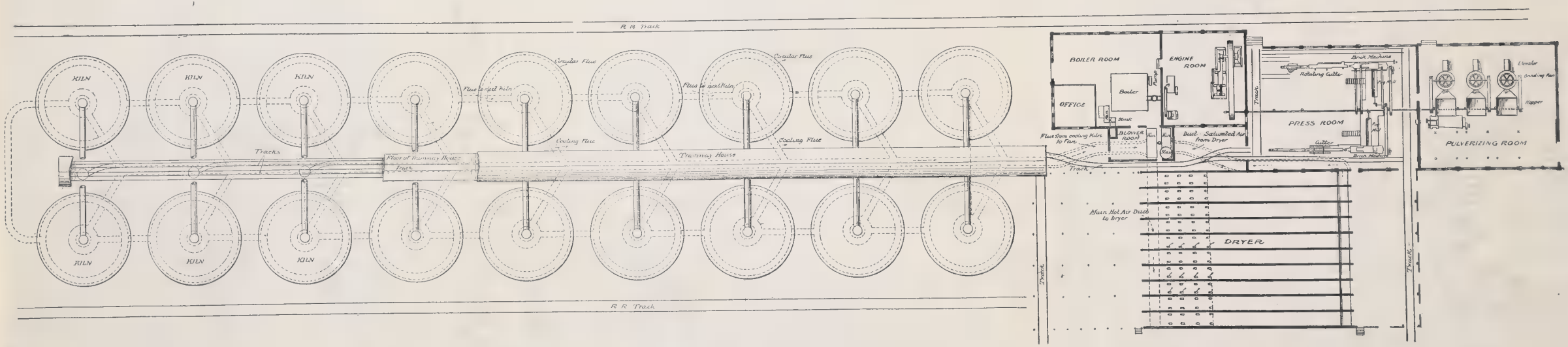
has assumed the responsibility of placing me upon the program, and I am pleased to have the honor of presenting a set of plans that I have made for the construction of a plant for the manufacture of sewer and paving brick. The drawings have been made in such detail by architectural draughtsmen that very little explanation is necessary. My experience has taught me that before starting to build, it pays to have every detail carefully drawn out on paper. However well one may have thought out or sketched out his plans, when he comes to assemble the complete details, he will run up against some conflicting arrangements and be obliged to make many changes, as one change generally leads to another. It is much cheaper to make these changes beforehand, on paper, than in wood and iron and brick after the building has been begun.

In planning a brick plant, due consideration must be given to the special purpose of the proposed establishment, and to the special local conditions, such as the size and topography of the site for the building, the location of the clay and the railroad, etc. These local conditions must always determine to a greater or less degree, the general plan to be adopted.

The plans herewith presented are for a paving brick plant, which it is expected will be built in the spring, about one mile south of this city. The shale to be used is situated above the level of the factory, to which it will be conveyed by a gravity railway. The direction from which the shale must come is directly opposite to that from which must come the spur from railroad for receiving coal and shipping brick. These facts necessarily influenced me in settling upon the general arrangement of yard.

I will describe briefly the equipment of the plant shown on the drawings:

The cars of shale enter the factory at an elevation of twenty-two feet and are dumped into hoppers built so that one man, by operating gates from below, can attend to the feeding of three or four drypans, — or the shale can be dumped outside of the hoppers in the storage room and fed to pans, in stormy weather, in the usual manner.



GENERAL PLAN

These pans are placed in the pulverizing room back of the press room in a row on a line parallel with the general progressive movement of the clay and brick, so that the clay is easily conveyed from the screens to a central hopper for feeding to pug mills.

The simple stationary inclined screens are used, the clay being elevated from pans to sufficient height to permit of these screens being twenty-four feet long. The width of each screen is six feet, and in order to secure a uniform distribution over the surface of so wide a screen, the clay is dumped from elevators into an U trough conveyor having an adjustable slot in bottom, over the screens. The tailings from the screens pass to the shale hoppers instead of directly to the pans. The screened clay is collected at the foot of the screens by a conveyor that carries it to the hopper above the press room.

The hopper for fine clays is in an upper room separated from the press room by dust-tight partition and floor, the lower part of the hopper projecting through this floor into the press room, and above and between the pug mills. This hopper is also an automatic feeder, supplying, when in operation, a constant uniform quantity of clay to the pug mills, making uniform tempering an easy matter. The capacity of this hopper and feeder is sufficient for the two largest pug mills shown on drawing. These pug mills are placed back to back, at right angles to brick machines, for convenience in receiving and discharging clay.

The brick machines are the standard auger type, largest size, with automatic cutting tables and separating belts.

In this special factory, one machine is to be used for making sewer and building brick, not repressed, and the other for the large size paving block demanded in this market. With the latter machine is shown one double die repress with capacity probably sufficient for this factory, when making these large blocks.

The cars, loaded from the separating belt or repress, pass to a transfer track, just back of the machines at the rear of the press room, and thence to the receiving tracks of the dryer.

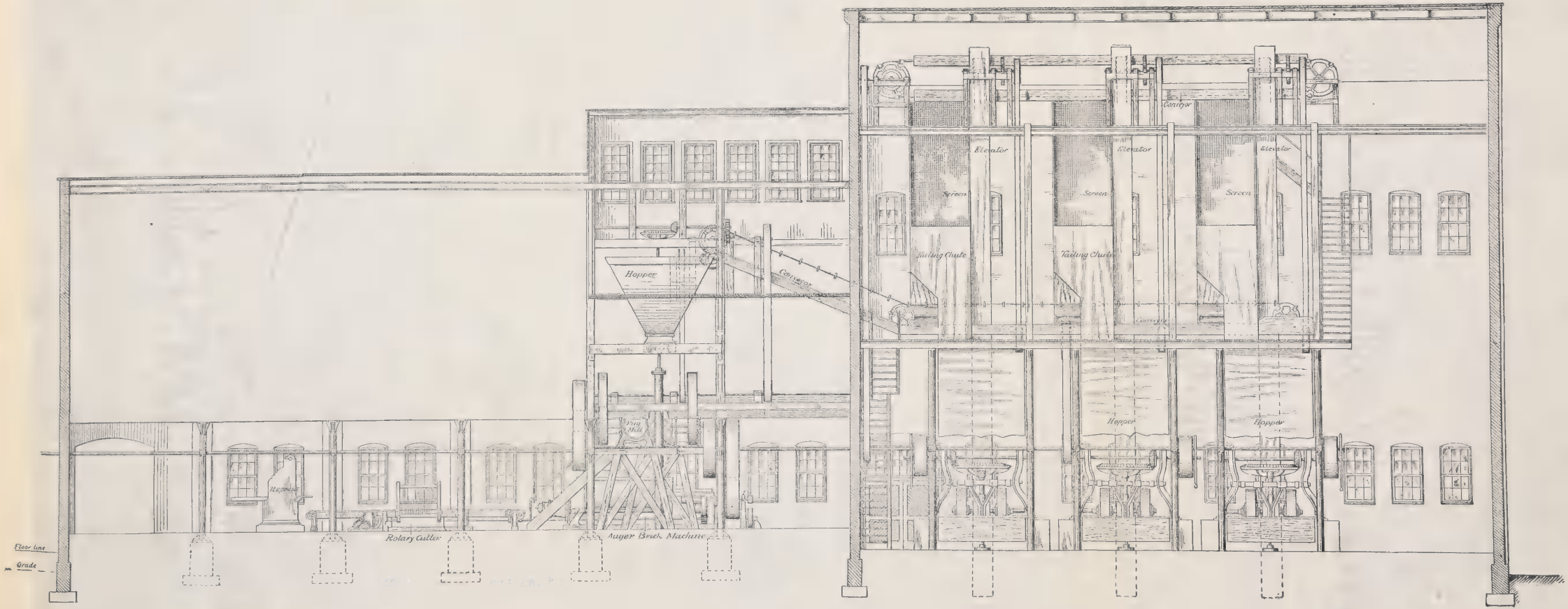
The power is transmitted to machinery by a line shaft extending through the center of the building and supported upon cast iron columns with brackets cast upon them.

The boiler room is situated at the lower end of dryer, at the head of the kilns, for convenience in receiving fuel and in furnishing steam for blower engine, and so as to utilize the combustion gases for dryer, if desired, and also exhaust steam. The boilers, of the water-tube type, have induced artificial draft, being connected so as to be operated by separate fan discharging into atmosphere, or by the dryer fan discharging into dryer.

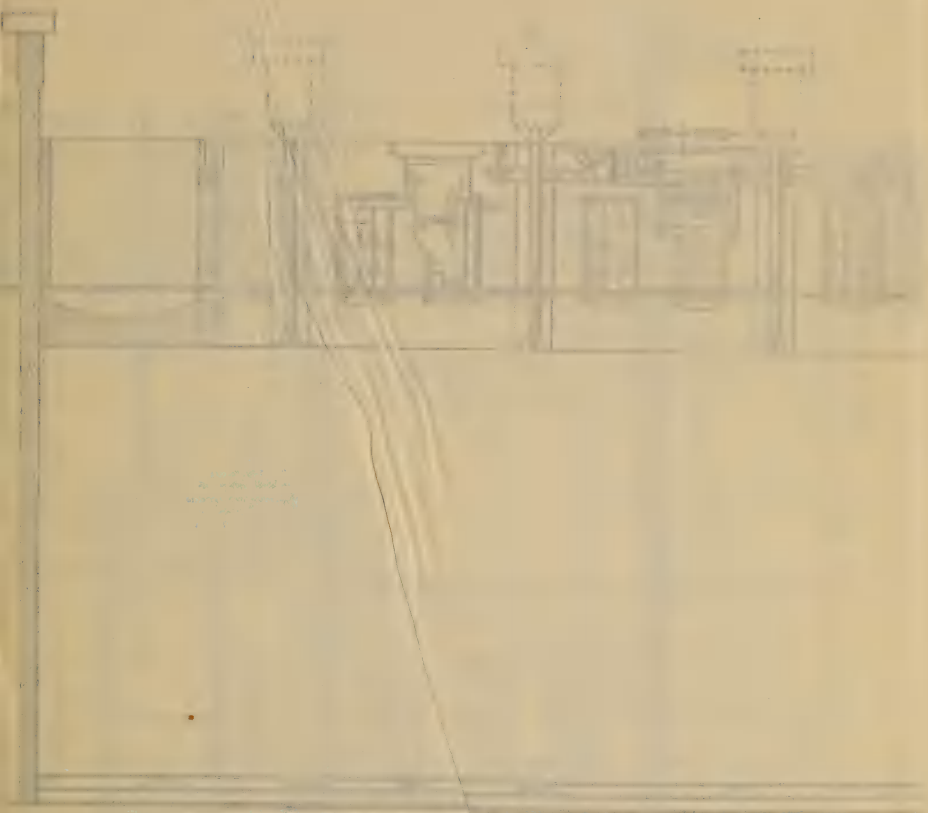
The engine room, between the boiler room and the press room, contains a 250 H. P. Corliss engine for running the factory, and an automatic engine for running generator, dryer fans and machine tools. The machine tools situated in engine room are lathe, planer and drill press. The generator is for running motors that operate fans for induced draft of kilns and also for lighting.

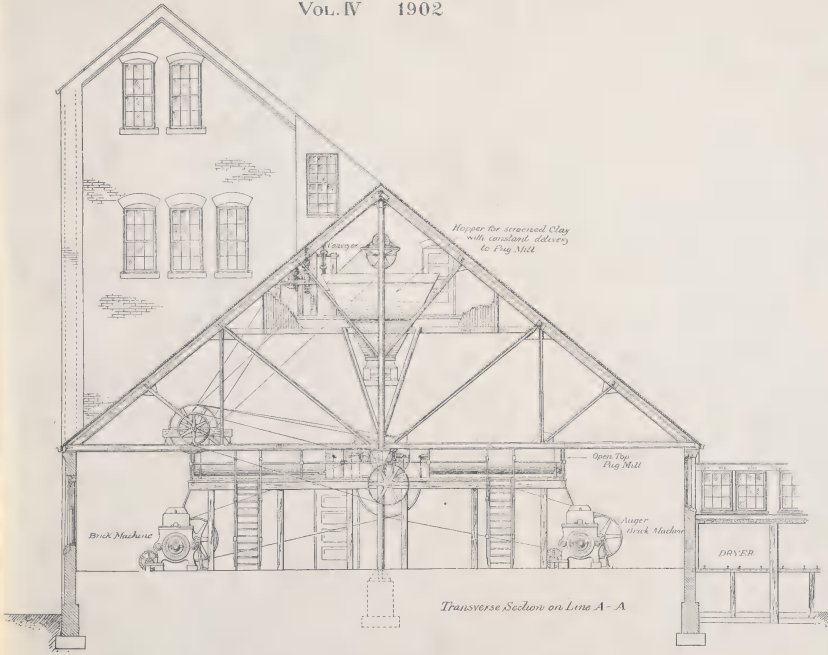
The buildings, you will notice, are practically fire-proof, the walls of brick and the roof framing of steel. This roof frame is covered with matched pine one and three-fourth inches thick and upon this, slate or roofing tile. The underside of the wood, between the rafters, is to be covered with two coats of lime whitewash, or other fire resisting paint. The floors are mostly of concrete and nearly all posts and beams of iron.

The dryer, constructed for the most part in the usual manner, consists of a series of tunnels separated by brick walls — each tunnel containing two tracks 100 feet long. The receiving tracks are twenty-three feet long and the cooling tracks forty-four feet long. The construction of the dryer is absolutely fire-proof, the roof, of course, being the special feature. Upon the top of the division walls, which are six feet and nine inches between centers, is constructed four inches of concrete, made from vulcanite cement, gravel and coal cinders, reinforced with a net work of iron strips. Upon this concrete is a course of hollow book tile laid in cement, and upon the tile is a gravel roof, the felt being stuck to the tile. This roof slopes from the receiving

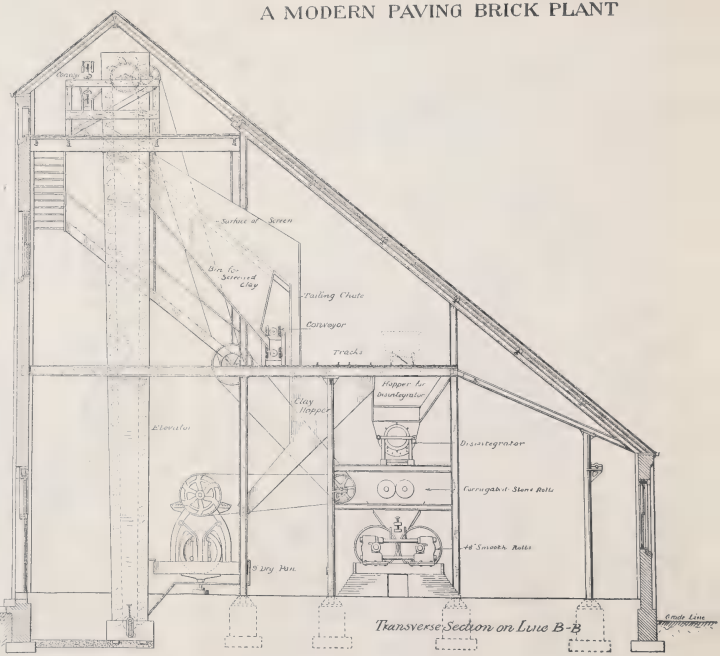


SECTION THROUGH BRICK MACHINE & GRINDING ROOM





BRICK MACHINE ROOM



GRINDING ROOM

end of the dryer to within ten feet of the discharge end,— one-fourth inch to the foot, this being the slope of the track in the tunnels. The last ten feet of roof at the discharging end is built up to slope backwards, forming a valley. In this valley are openings into 4-inch conductor pipes laid in each wall, and passing downward to the sewer pipe drain below.

The special feature in addition to the roof construction is the slope of one-fourth inch to the foot in the tracks from the receiving end, the last ten feet being level, and the method of moving the cars through the tunnels. The details of this latter are not shown on these plans, but can be briefly described.

The cars are coupled together automatically when placed in the dryer, so as to insure no break in their ranks as they move by gravity down the decline. At the bottom of the decline is a device for braking and stopping the cars. By throwing a lever just outside the entrance of the tunnel, the forward car on any track is disengaged and the car back of it is blocked. After the forward car is removed, the lever is reversed and the other cars let down and blocked, each car being uncoupled automatically about ten feet from the end of the dryer. Thus one car is always free to be removed from dryer, and a car can be put into dryer at receiving end without the necessity of pushing other cars.

The heat for drying is obtained from cooling kilns by means of a fan — the distribution of heat being in the usual manner. The special feature, however, is that the saturated air is removed from the dryer through an underground flue by means of a fan coupled with the fan that furnishes the hot air, both fans being upon the same shaft and driven by the same belt, the driving pulley being in the boiler room upon the shaft extending from the engine room.

In making plans for a brick plant, especially for the manufacture of paving brick, one's chief study must be in designing the kilns for burning. In no other department of brick making, is there greater need of improvement, notwithstanding the large number of patented kilns on the market. Many of these patent kilns possess positive, dis-

tinct points of merit and are well adapted for special situations, but the trouble is that each advertiser recommends his kiln for all purposes and situations. However, I could find no kiln advertised that would meet my requirements for a modern paving brick plant.

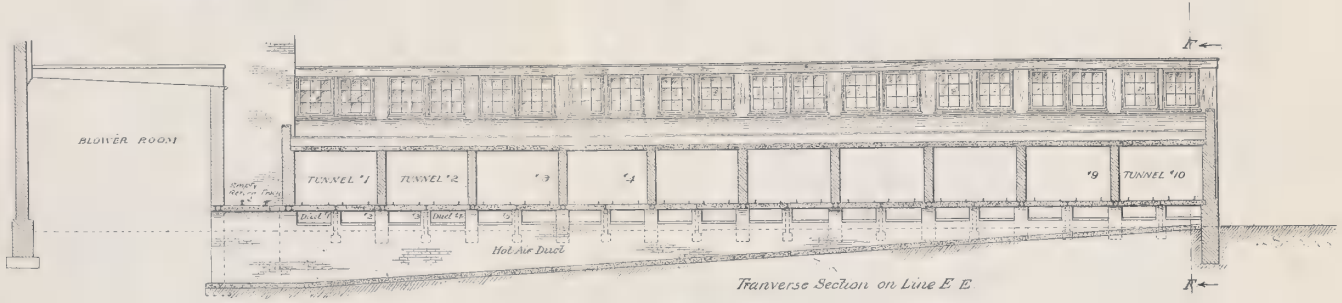
The kiln for my purpose must have the following features:

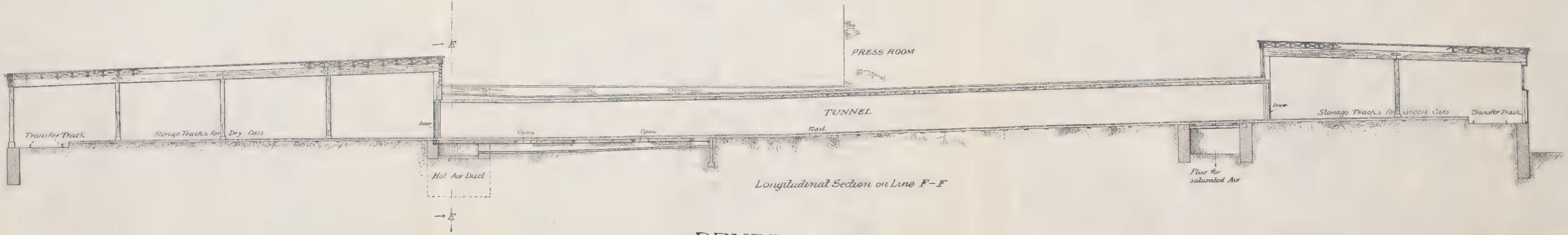
1. Down draft.
2. Uniform distribution of heat.
3. Economical in operation, saving fuel, labor and time, and so constructed as not only to utilize waste heat, from cooling kilns for transmission to dryer, or for heating air for combustion in kiln furnaces, but also it must utilize the waste heat escaping from the hot burning kilns in heating up other kilns. In other words, it must have the advantages of the continuous kiln, without its disadvantages.
4. Durability — costing little for repairs.

The first question to be determined was whether to have separate kilns, each of which could be burned independently, if desired, or to have the several ovens or chambers so placed in juxtaposition as to preclude one being burned independently of the others. I was influenced somewhat in this by the judgment of friends who have had large experience with continuous kilns, and also by the fact that in building separate kilns, I would be following along the line of my previous practice, and would feel more confident of such results as I wish to obtain. I do believe, however, that a continuous kiln can be built that will be highly satisfactory for paving brick.

Having decided upon separate kilns, the next point to determine was the form of the kiln — whether round or rectangular. My experience with both forms enabled me to decide at once in favor of the round kiln, chiefly for two reasons:

1. Because the round kiln is less expensive in first cost and especially in repairs.
2. Better distribution of heat and fewer underburned brick.


BLOWER ROOM
TUNNEL '1
TUNNEL '2
'3
'4
'9
TUNNEL '10
Hot Air Duct
Tranverse Section on Line E E


PRESS ROOM
TUNNEL
Transfer Track
Storage Tracks for Dry Cars
Door
Open
Open
Rail
Hot Air Duct
Door
Storage Tracks for Green Cars
Transfer Track
Flue for saturated Air
Longitudinal Section on Line F-F

DRYER

The stack question came up next for consideration — whether one or more stacks, and where situated. You will notice that I decided upon the single stack in center of kiln. The advantage of this arrangement are:

1. High temperature of stack, hence a low stack.
2. Heating up the stack from the first firing means a strong draft in the early part of burning, giving freedom from whitewash and shortening of time of burning.
3. A kiln of larger diameter with hard brick to the center.

The disadvantage of stack in center of kiln are:

1. Inconvenience in setting.
2. Space occupied in kiln.

These disadvantages I have found not so great as I first thought. The stack in the center of a large kiln is not much in the way — in fact, hardly more in the way than a stack in any other place. The space occupied in the kiln is for a thirty-foot kiln only about two per cent. of the inside kiln space and for a thirty-six-foot kiln, about one and one-half per cent.

The special feature of the kilns for this plant is the system of utilizing the hot gases escaping from the burning kilns for heating up other kilns, and likewise of using the cooling kilns for heating the air for combustion. To accomplish this the kilns are connected by an underground flue, extending from the center of each kiln to a circular distributing flue in the next kiln ahead. This circular flue is in the hub of the kiln, with openings into each fire box, adjustable by dampers. The movement of the gases is induced by a fan connected to the stack of any kiln by a cylindrical steel flue, as shown in drawing. The fan is portable, being erected upon a car moved along an elevated track between two rows of kilns and operated by an electric motor directly connected.

I calculate in this manner to be able to draw the heat from a hot kiln through at least two other kilns and that by the time that the kiln under fire is finished, the kiln just ahead will be partially or wholly incandescent, so that heavy fires can be put into the furnace at once. There will thus

not only be a saving in fuel, but a considerable saving also in the time of burning.

Whether I accomplish all that I expect by this system or not, I am confident that I can accomplish enough to more than pay for the additional expense of construction. However, each kiln can be burned independently by natural draft, if desired.

Now, gentlemen of the American Ceramic Society, I have given you the result of my thought and experience upon the subject assigned me. I have no interest in influencing anyone to adopt any of the suggestions I have made. I have tried to do my duty in presenting this paper, and I hope to have the benefit of your criticisms.

DISCUSSION.

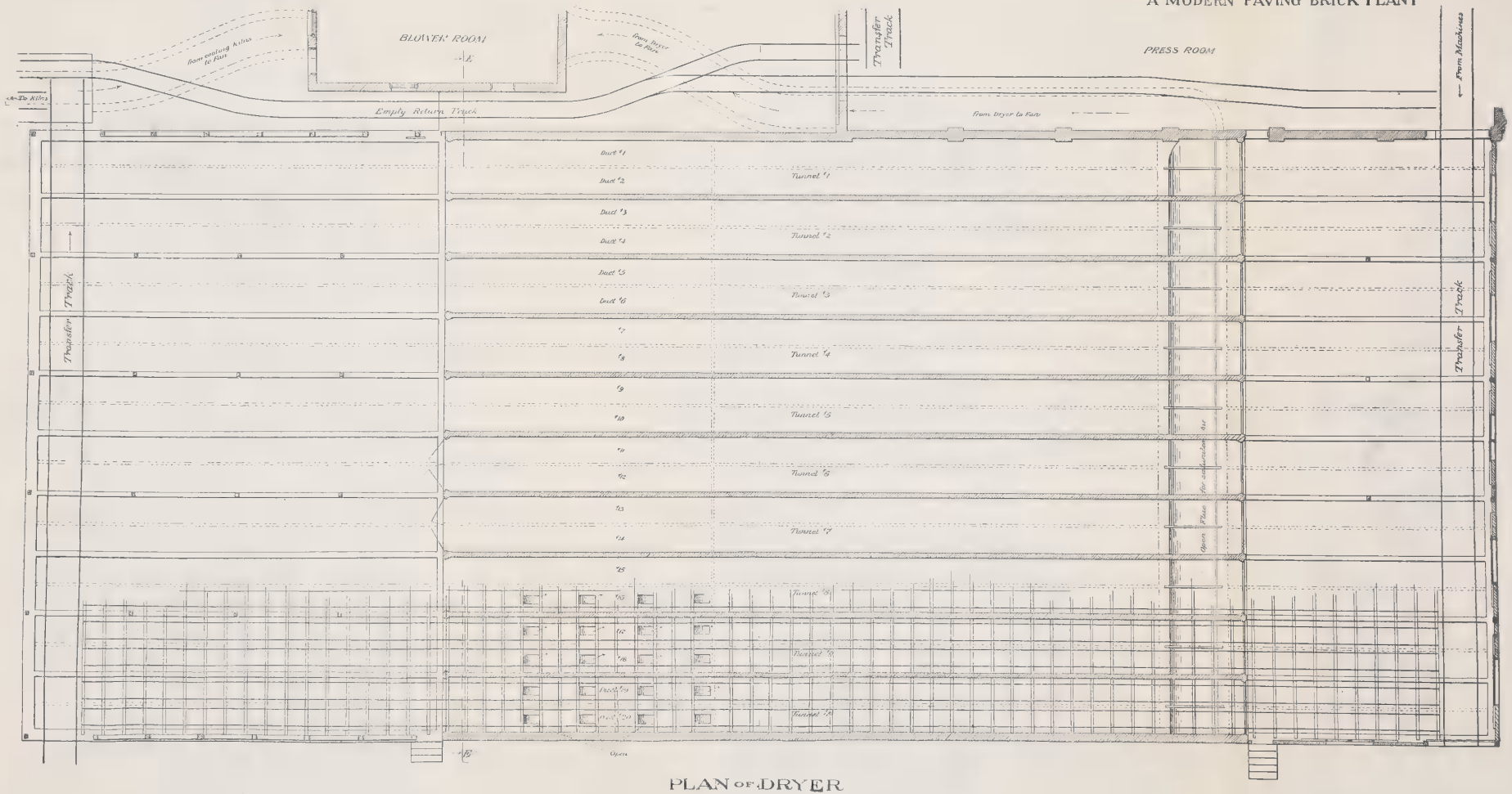
Mr. Lemon Parker: How much grate surface do you provide as compared with the size of the kiln?

Mr. Richardson: I have not gone into many of the details, because I did not know whether it would be of sufficient interest to those who would listen to it. There is really no grate surface at all. These are thirty-six foot kilns, with twelve furnaces to each kiln. The fire-hole is two feet wide, without grate bars. As shown in the plans, the firing door is covered in the usual manner with a fire clay slab, reinforced with iron bands. The coal is thrown upon a coking table, made partly of cast iron and partly of fire-clay tile and shoved down upon the fire just before a fresh supply of coal is added. A furnace, similar to this, is used quite a good deal in Ohio, but this drawing here is not exactly, perhaps, as I would make it for this kiln. Since this drawing was made, I have built furnaces which I think are better than these. But they are built on the same principle — down-draft furnaces, with a coking table and no grate bars.

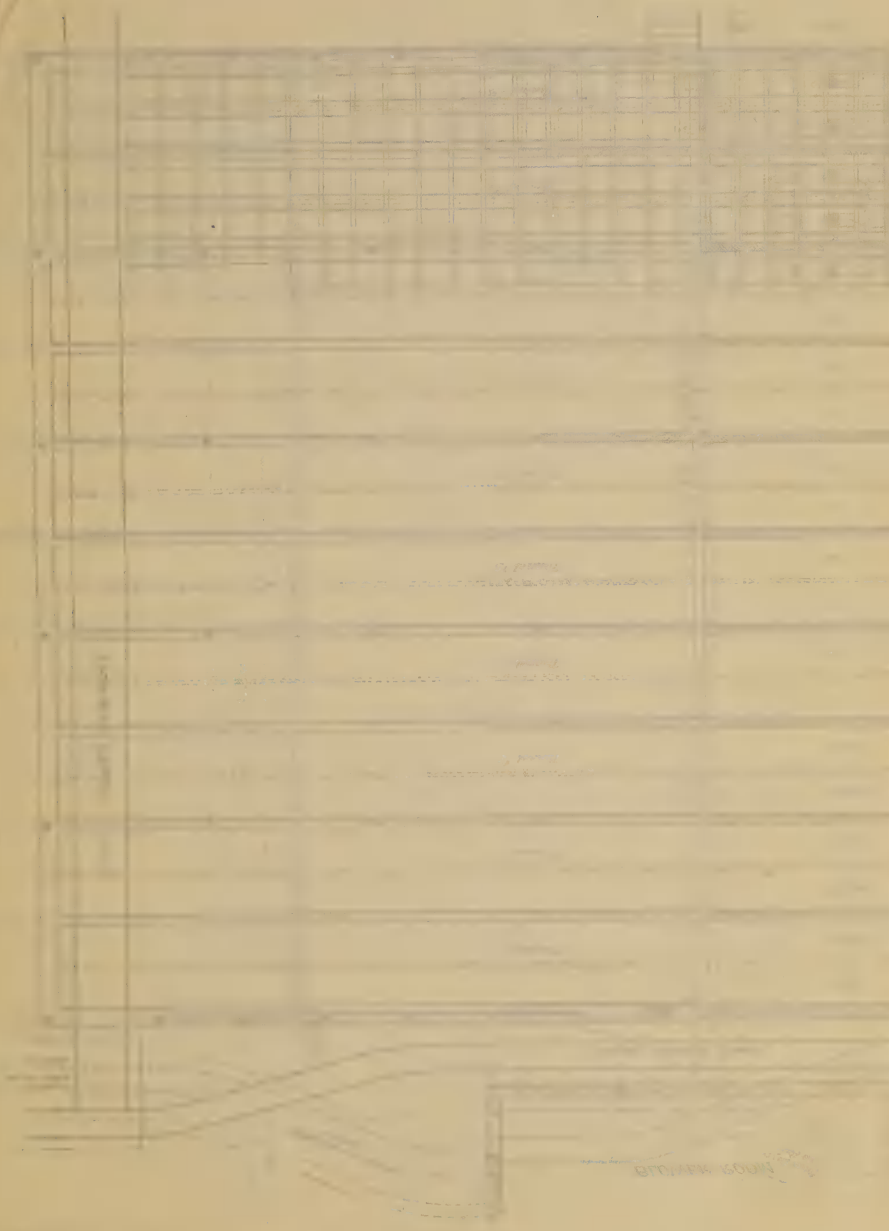
Mr. Parker: We use fourteen fire boxes for a twenty-five foot kiln.

Mr. Richardson: Many people will not use as many fire boxes as I have shown here. I never built a kiln larger than thirty feet; on that, I used ten fire boxes, and had no trouble in getting plenty of heat in the kiln.

RICHARDSON
A MODERN PAVING BRICK PLANT



PLAN OF DRYER



Mr. Parker: What cone did you burn to ?

Mr. Richardson: In the kilns I referred to, we burned iron mottled, fire-flashed brick, cone eight down, on the bottom.

Mr. Parker: We burn cone ten.

Mr. Richardson: That is a higher temperature than is usually required in the brick business. Still there would be no difficulty in getting that temperature. But probably if you require that temperature, it would be well to have wider furnaces, or more of them.

Mr. J. Parker B. Fiske: I have been exceedingly interested in this paper and in the drawings, not only on account of their technical value, but because it seems to me this paper marks an era in the brick manufacturing world. We have had presented here a carefully prepared set of plans for a brick plant, based on an experience of many years in brick manufacture, and worked out by a competent engineer. The mechanical engineer up to the present time has not applied himself very largely to the designing of complete clay-working establishments, particularly those for manufacturing brick.

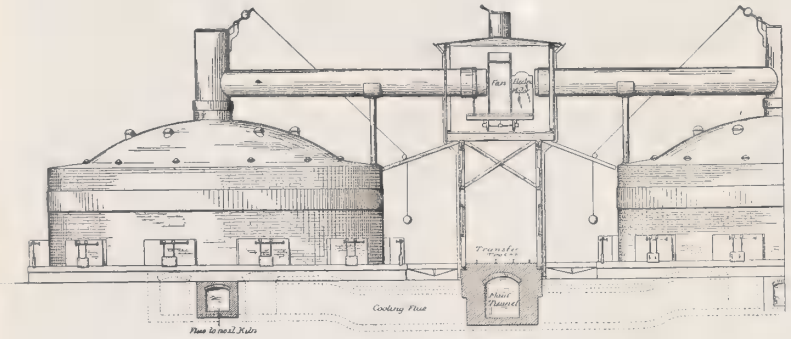
The manufacturer, as a rule, has had to gather such points as he could from his neighbors, coupling with these his own experience, and then with a very meagre set of plans (if any at all), has had to commence the construction of his plant. And I venture to say that the average brick plant, which, like Topsy, just grows, without any predetermined plan, is hardly ever well commenced before the builder finds that some things are wrong, some parts don't work together to advantage, and he wishes he had built differently.

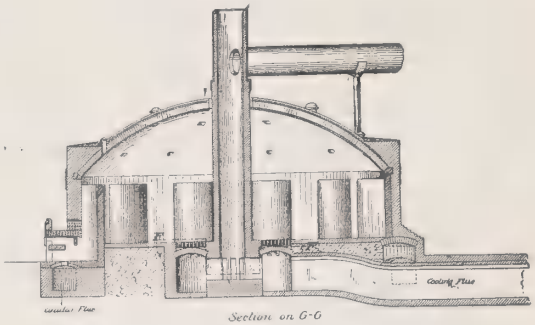
Now, the building of any large manufacturing establishment today, outside of brick-making, is rarely ever undertaken without the most careful consideration of every feature entering into the construction and operation of the plant. A modern steel or cotton plant is designed by the most competent engineers before anything else is done. I believe that the losses which the brick manufacturer suffers today, more or less in every plant, are largely due to the

fact that the whole arrangement is not carefully considered on paper, before building is attempted. Now, of course, no matter how carefully a plant is worked out on paper, there will be some things discovered during the process of construction on which should be altered; but with a careful consideration in advance of every feature of the complete plant, as in this case, from the arrival of the raw clay to the finished product, there cannot fail to result economy of labor, economy of fuel, and cost of maintenance far ahead of that in a plant otherwise erected.

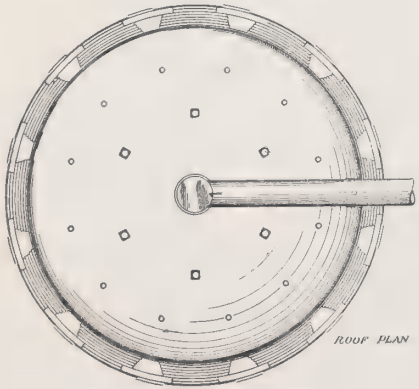
There are many points about this plan in which I am interested, and which I would like to discuss with Mr. Richardson, but I will not take the time of the society for that. I would like to ask one or two questions, however: One is, what particular advantage Mr. Richardson sees in the arrangement of isolated kilns, coupled together for continuous operation, over the construction of a kiln where the chambers are all built in one structure and operated continuously?

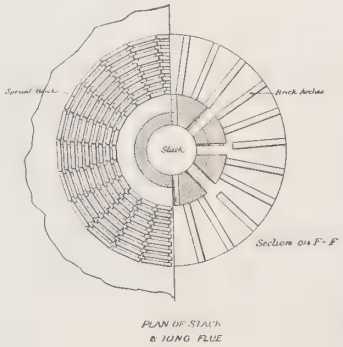
Mr. Richardson: Well, as I stated in my paper, I do believe that a continuous kiln can be specially designed to burn successfully any kind of product. But, in making plans for a plant in which you are to put your own capital and that of your friends, you feel that you dare not be too radical for fear that something might be wrong somewhere. I have, in fact, gone all over that question. I have been first on one side and then on the other, and I have tried to include the advantages of both systems as far as possible. The advantage of this plan is that any kiln can be burned separately, independent of the rest of the plant whenever it is desired to reduce the output or to make repairs; and also, that for paving bricks, probably better results can be obtained. The vitrification and proper annealing of paving brick no doubt can be done in a continuous kiln, but there were too many questions in my case as to just how it was best to do it, and whether it would be a decided success. I know the continuous kiln is being used for paving brick in a few places, but to the best of my information, not

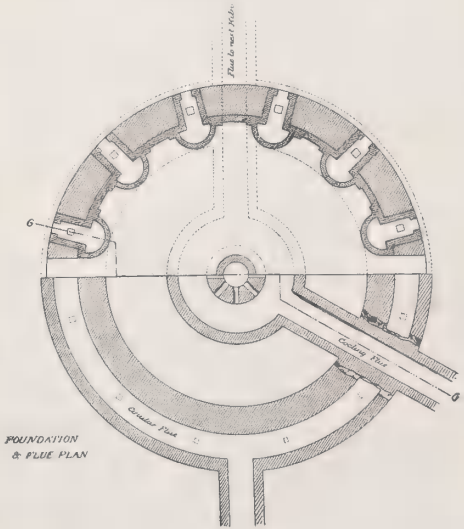


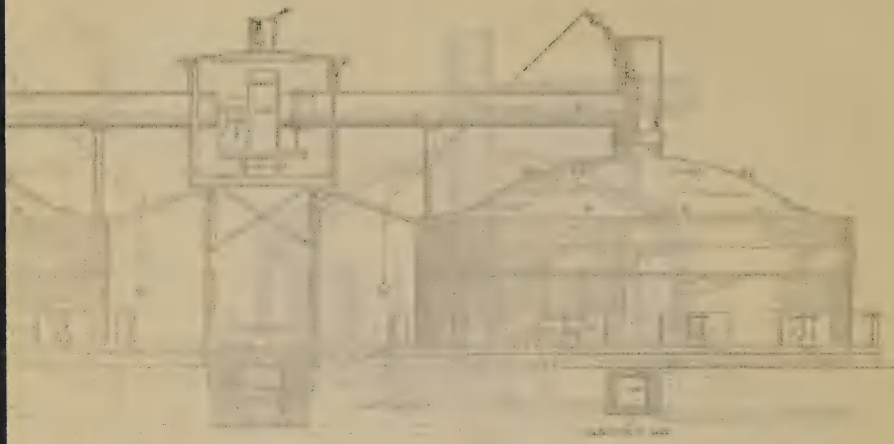


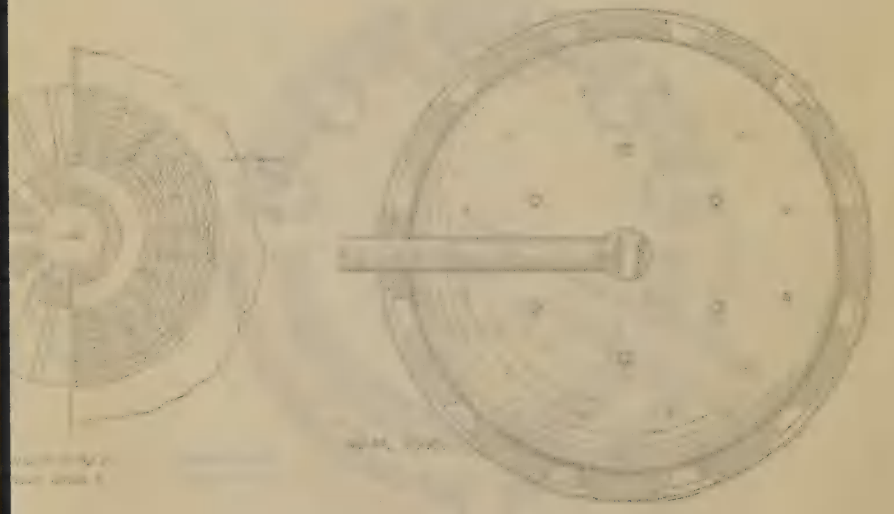
GENERAL ELEVATION OF KILNS











as successfully as the down-draft kiln. It may be owing to the fact that the continuous kiln is not properly designed for this special purpose. I am a little inclined, myself, to go wholly into the continuous kiln line, but have been afraid to take the risk in such a plant as I have here designed and where all depends on the efficiency of the single kiln system.

LEAD FRITTS AND THEIR ADAPTATION TO POTTERY GLAZES.

BY

WILTON P. RIX, New Castle, England.

The attention of the English potters has of late been directed to the relative value of lead in a raw and fritted state, by the proposal to enforce regulations forbidding the use of raw lead in the manufacture.

Statistics support the statement made that the use of fritted lead reduces the noxious quality of the glaze, but it has been shown, beyond doubt, that in order to obtain complete freedom from plumbism, it is necessary that the lead contained in the fritts used should be insoluble in dilute hydro-chloric acids; that is, that the lead should be present only in the form of bisilicate or compound silicates complying with the above tests.

This matter has really assumed still greater importance owing to the comparative failure of the attempts made by a number of the English earthenware manufactures to obtain satisfactory leadless glazes, capable of being worked under the ordinary conditions. The average loss has been found considerably greater with the use of such glazes than in the case of those containing lead, owing to the greater care required in the manipulation and firing such glazes.

In attempting the substitution of fritted lead glazes for those compounded with raw lead, various important considerations arise with regard to their adoption. These relate to apparent disadvantages which has been raised against them; also to the possibility of adjusting the fritts to the present requirements of the various branches of the trade.

The objections may be summed up as follows:

First. The additional cost involved in fritting as regards fuel, wear and tear and labor.

Second. The loss of lead by evaporation and absorption in kiln fritting.

Third. The difficulty of producing insoluble fritts of sufficient fluidity to allow of their introduction into the softer glazes, without a sacrifice of the brilliancy and soundness of the glaze.

Fourth. The increase of the difficulty of manipulating and firing such glazes.

With the adjustments of such fritts to the present glazes and conditions, the question at issue may be stated as follows :

The continental potters appear to have realized that the use of fritted lead assists the immunity of the lead worker from plumbism; indeed many of them have adopted fritting with promising results, while a few of the most important works have produced glazes from fritts of very low solubility.

The temperatures at which such continental earthenware glazes are matured vary from 06 to 01. The temperature for maturing English earthenware glazes varies from code 05 to cone 03. The percentage of lead used in English earthenware glazes varies from 18 per cent. to 25 per cent. The percentage of lead used in English china glazes varies from 3 per cent. to 20 per cent. The percentage of lead used in English majolica glazes is from 35 per cent. to 55 per cent., or even 60 per cent. The temperature for maturing majolica glazes varies from cone 010 to cone 05.

These being the existing conditions the questions arising are:

First. Does the substitution of lead fritts as in raw lead involves any alteration in actual properties of the glaze components in order to obtain results similar to those of raw lead glazes?

Second. Does the use of fritted lead involve any increase of firing temperature, or any different method of carrying on the firing process?

Third. Is the fluidity of the glaze affected by the character of the lead fritts used; that is whether bisilicate or double silicate or compound silicate is used?

Fourth. Can glazes of sufficiently high fusibility be obtained for the manufacture of plumbiferous majolica

glazes, fired at Seger cone 010, when these are compounded of lead bisilicates or double silicates, the maximum solubility of the glaze not exceeding, say 3 per cent.?

Fifth. How far is it possible to introduce other fluxes into the fritt mixtures, thus increasing fusibility and yet still maintaining the requisite insolubility of the lead present: and having also due regard at the same time to the effect in use of such fritts?

(*a*) On the working properties of the glaze in firing.

(*b*) On the tints of colored majolica glazes.

(*c*) On the fluidity of the glazes when fired at the customary temperatures.

On many of these points the English manufacturers appear at present to be at variance. Some imagine that the use of lead fritts cannot be carried out: while others show satisfactory results and have no objection to raise as to their adoption. Probably this discrepancy arises from varying conditions coupled with a want of efficient manipulation, and also insufficient attention to details in the case of some who have failed.

It is obvious as regards the use of lead fritts in the glaze that the lower the firing temperature, the greater the amount of lead required. When this amount exceeds that present in a bisilicate fritt, new difficulities arise in the production of a double or compound silicate, capable of holding in combination such fluxes other than lead as will affect the necessary fusibility of the fritts and consequently of the glazes.

It will be seen that various other existing questions are involved which will readily suggest themselves to members of the society, and on which at present little accurate information exists, but those mentioned above are more than sufficient to occupy the scope of the present paper. I therefore propose to limit the discussion to the points first named.

(1) *The possibility of substituting lead in fritted form for raw lead without change of proportions used.*

On this point my experience does not bear out the statement made by some manufacturers, that more lead is

required to produce the same results if introduced in the form of fritt. I have made comparison of the same glazes worked under both methods side by side in the same saggers, and have repeated these in different ovens. The results do not vary in any substantial respect provided that the total contents of the glaze remains the same, and the calculations of the new formulæ are accurately carried out—the raw and fritted glazes for the lead may be substituted for raw lead.

(2) *Does the use of fritted lead involve any increase of firing temperature?*

Provided the total contents of the composition of the raw and fritted glazes are the same, the raw and fritted glazes will be found to fuse at the same temperature. There is, however, some indication that some lead fritts take longer to mature in firing than others. The point of incipient fusion must also be placed somewhat higher as regards temperature. There is evidence of this fact in composition of fritted glazes now in use on the continent by some important manufacturers, who add a very small percentage of raw lead to the glazes, obviously for the purpose of promoting the incipient fusion at a lower temperature. I attribute to these questions of incipient fusion and length of firing, the difference of results obtained by various potters. It is probable that the firing is carried on by different methods, or that the uniformity of heat in various positions in the oven is less with some than with others.

(3) *Is the fluidity of a fritted lead glaze affected by the character of the lead fritt used; that is whether bisilicate, double silicate or compound silicate.*

On this point there appears to be strong evidence that the fluidity is thus affected: that is, apart from the question of fusibility the glazes when fused are more or less viscous, according to the composition of the fritt. It is, however, open to further research to demonstrate how far this fluidity of the glaze at a good temperature if affected by the heat at which incipient fusion takes place, and also by the length of time required to mature the glaze in firing, without increasing the temperature. This issue is one of considerable importance to the potter in adopting fritted glazes for use on

goods printed under glaze. My own experience over a limited area is that double silicates of lead show less fluidity than bisilicates if worked under the same conditions, the equivalents being of course duly regarded in the fritt composition.

(4) *Can glaze of sufficiently high fusibility be obtained for majolica colors, firing at cone* 010 *by the use of bisilicates or double sicicates of lead, still maintaining a solubility not exceeding, say three per cent.*

Before discussing this question it is necessary to define the amount of fluidity required in the glaze. For plain tiles, needing only uniformity of color and texture, the property of extreme fluidity and transparency is often less important than in the case of finely modelled relief tiles and blended glazes, in which the artistic effect is mainly due to the falling of the glaze into the deep hollows, and the ready mingling of the colors with each other during the firing.

In the latter case considerable difficulties arise in producing suitable glazes with bisilicate lead fritts. Many glazes now in use for this purpose contain as much as fifty to sixty per cent of lead oxide, and it is obvious that even supposing the bisilicate fritt by careful preparation is obtained under two per cent. solubility, the high percentage of lead contents required in such glazes leaves no room whatever for the introduction of other glaze materials to improve its working properties.

It must also be pointed out that the method adopted of obtaining some colors by the dilution of a boro-silicate colored lead fritt with transparent lead glaze, is no longer available when the two per cent. solubility is exceeded, and even if the raw lead is replaced by lead fritt. The high solubility of such boro-silicates forbids their use in these conditions, such as the difficulty of obtaining low solubility with sufficiently high lead contents in the glaze to insure the extreme fluidity on which the beauty and richness of many soft majolica glazes depend. In this branch it appears to me there is ample scope for further research, and it is probable that eventually the introduction of a new pallette of

colors may be involved — or a new type of decoration less dependent upon the property extreme fluidity.

In discussing the above questions it must be understood that the production of glazes having a maximum solubility of two per cent. has been kept in view, and also the maintenance of existing conditions in English pottery manufacture as to composition of glazes and firing temperatures, and adaptation to existing bodies.

The difficulties are obviously much diminished as the firing temperature is increased, because the lead contents of the glazes can then be proportionately dimished.

DISCUSSION.

Professor Charles F. Binns: This lead question has been an interesting study, and has cost English manufacturers a good deal of heart-burning and anxiety. One important point has been brought forward in the relative solubility of lead fritts. It is found that lead fritts are more soluble with boracic acid than without. This was proved out by a Belgian manufacturer. I doubt if this fact will affect the bulk of small manufacturers in England, for they are troubled enough in making one fritt, without making two. It is scarcely known here how far the practice exists among the smaller English manufacturers of buying ready-prepared glazes. Quite a number buy it ready prepared and have no more idea what is in it than the man in the moon. This operates against anything like a change in glaze. As the matter stands now, the English manufacturers have been given eighteen months in which to make experiments, and my view is that the burden has been materially lightened as to the potter.

I want to say a word about Mr. Rix's last remark regarding the expansion of the ceramic society. The North Staffordshire Ceramic Society has been established since we have been in existence. How far they have thrown their net around the manufacturer, I do not know. They meet once a month for the discussion of minor problems; and I have wished sometimes that we could meet once a month and have one thing at a time. We are in great danger of ceramic dyspepsia from the full meal we have had here.

One more point. I wish Mr. Rix had defined his bi-silicate and double silicate and compound silicate. We ought to have further information on this point.

Mr. E. E. Gorton: My experience differs somewhat from Mr. Rix's on one point, in regard to the fritting of the lead. I have found that where lead is fritted, and the glaze is not a boracic-acid glaze, it does require a higher equivalent of lead to get the same results. I presume it is due to the volatilization of lead in fritting.

Professor Binns: I ought to make another remark. This question of the solubility of the fritt created quite a good deal of disturbance. The English regulations required the inspector to take samples from the dipping tub, and if he found more than two per cent. of raw lead the manufacturer could be brought to account. The point has arisen as to what constitutes solubility. Mr. Jackson carried out a line of experiments and found that solubility was directly commensurate with the size of grain. By repeated grindings, he found he could dissolve more and more as the fritt became finer, and it seemed that if he could go on long enough he could dissolve the whole. His conclusion was that a coating of insoluble lead was formed on the grains of fritt, and that the grinding removed this each time.

Professor Orton: Wouldn't they be driven to construe the question as to the amount of lead in solution in the dipping tub?

Professor Binns: Yes — not in solution in the dipping tub, but in suspension. The per cent. of raw lead in the dipping tub is one thing and the solubility of lead fritt is another. The government said, "You must not use more than a certain per cent. of raw lead." The manufacturer laid, "We can't make glazes with that amount." Then the question arose, could not the lead be rendered insoluble. It was suggested that by fritting it might be rendered insoluble. They can use raw lead in the dipping tub, providing it is not above a certain amount.

Professor Orton: Does English legislation forbid the use of a glaze in which more than two per cent. of lead is soluble?

Professor Binns: That is what was proposed. We were obliged to provide overalls, caps, nail brushes, soap, towels, etc., in order that the men and women should be compelled to wash themselves, and clean their nails. The whole trade is in revolt owing to this ill-judged and "grand-mother" legislation, from which we in the United States glory that we are free. The next point which arose was in reference to a series of rules embodying the limits of raw lead which could be used. The investigation which was made has entirely broken down on the government side, and it has nothing to say at present, though it may have eighteen months hence. It has been demonstrated that if the regulations are enforced the whole pottery industry of England will be killed.

Mr. Burt: I always understood that the poisoning, as a rule, was due to the inhaling of lead dust. I don't see any direct connection between lead dust and the question of solubility, whether two or three per cent. is in solution.

Professor Binns: The issue is somewhat simple. It is due to the effect of the juices of the body, particularly the gastric juice upon the lead oxide; and the effect of dilute hydrochloric acid is considered to be the same as that of the gastric juice. The point was whether lead oxide, if soluble in hydrochloric acid, might not be absorbed by the skin. Not only might this be so, but sometimes the work-girls would carry candy in their pockets and feed themselves while their hands were covered with lead. It gets into their hair, and the body pores can take in a vast amount of the lead salts. The effects are shown to vary with different persons. I have known a case where a girl was put to work trimming a porcelain glaze not containing more than four per cent, of lead oxide, and she sickened in a week. And there are cases where women have worked twenty years and not felt the slightest ill effect. It is largely a matter of tempermanent, and we always made it a rule when anyone showed any signs of sickness to put them elsewhere, only keeping in that department those who showed themselves to be immune.

THE STRUCTURE OF SILICATE MIXTURES.

BY

HARRISON E. ASHLEY, S. B., New Bedford, Mass.

"Based upon the microscopic examination of thin sections of minerals and rocks, observations were recorded in 1858 by Dr. H. C. Sorby, member of the Iron and Steel Institute, in a paper on the microscopic structure of crystals, indicating the origin of minerals and rocks (Quarterly Journal of the Geological Society, vol. XIV, page 453), and in October, 1867, by the late Mr. David Forbes, member of council and foreign secretary of the Iron and Steel Institute. These observations gave birth to the special science of petrography." *

"From the introduction of microscopic methods of investigation up to a date about eight or ten years ago, the energies of practically all students of the subject were devoted to observing and recording mineralogical and textural differences, and the subject of chemical composition received but slight attention. It was revived, however, toward the close of the eighties by W. C. Brögger, then in Stockholm, and in the course of time has received wide recognition and employment from many others.

Petrographers are now accustomed to recast an ordinary chemical analysis by dividing the several percentages by the molecular weights of the corresponding molecules, so as to obtain a series of numbers, which are called the 'molecular proportions' or 'molecular ratios.' These quantities indicate the relative numbers of the several molecules in the rock magma, and in that respect are more significant than are the percentages. . . . . The molecular composition of the common rock-making minerals are now quite accurately determined and understood, and using them

* The Metallographist, (1902), 5 [2], 146.

it is often possible to calculate from the molecular proportions furnished by a rock analysis, the percentages of the several minerals in the rock. The calculations are usually checked in a general way by a study of thin sections." *

In a recent joint report by W. H. Weed and L. V. Pirsson, † the latter presents recalculated analyses of a large number of igneous rocks. He first ascertained by microscopic examination what minerals were present; then from chemical analysis and molecular proportions what percentage of the several minerals were present. Prof. J. F. Kemp, the author of the article on 'The Re-calculation of the Chemical Analysis of Rocks,' from which the two preceding paragraphs were copied, shows in detail in that article the method of recalculation.

The present writer, in an article § on slag-constitution, has shown that the freezing or melting points, or less exactly, the formation temperature, or the total heats of solidfication will show the constitution of such mixtures at the temperature of fusion.

Chemical methods of separation, taken by themselves, have not been very successful in showing the structural constituents of silicate mixtures.

It is most satisfactory to rely, not on a single method of investigation, but on the joint use of several methods. It is desirable to supplement chemical analysis and fusibility determinations by microscopic examination. The latter often presents special difficulties. The slag or ware may be unsuited for the preparation of thin sections, or if suited, few persons have the necessary equipment for their preparation, or considerations of time and expense may be prohibitory. Silicate mixtures are seldom examined on the surface of thick pieces by reflected light, as it is difficult to find any apparent differences of structure. With metals and alloys on the other hand, surface examination by reflected light is

* School of Mines Quarterly, (1900), 22, [1], 76.

† Geology of the Little Belt Mountains, Montana, by W. H. Weed, with a report on the Petrography by L. V. Pirsson, XX. Ann. Rep. Dir. U. S. Geol. Survey, III., 257.

§ Slag-Constitution. studied by means of the Tri-Axial Diagram, with Rectangular Co-ordinates.—Trans. Am. Inst. Min. Engineers. Nov. 1901.

the universal method. Differences in structure are shown by the unequal action of polishing agents, of etching agents, and of oxidation, or other coloring effects. With silicate mixtures, so far as the writer knows, nothing has ever been accomplished by differences in wear or by development of colors, and but little by etching with fluorides or alkalies.

A phenomenon met in laboratories may offer a means of progress. The writer has frequently noticed that the first portion of vapor condensing on a cold glass surface, for example, the underside of a watch-glass upon a beaker whose contents are being heated, is not uniformly distributed over the whole surface, but is in small patches. Each of these patches seems to be uniformly covered, and differs in density from the patches touching all around it. The whole effect resembles the microstructure of a slowly cooled very crystalline metal. Each patch of moisture may indicate the extent of the external surface of one crystal* of the glass. With further condensation the differences are obliterated.

It seems likely that the first microscopic deposit may be more highly differentiated than that that appears to the naked eye, more destinctive in character, and more certain of positive appearance. While water vapor is a fugitive medium, there are multitudes of definite chemical substances capable of being sublimed with the formation of fairly stable deposits.

It is possible that the selective action of the silicate mixture crystals may even go so far as to attract or retain, substances having the same crystal system and molecular volume, while rejecting substances of unlike properties. This may open a way for the study of molecular weights of solid substances.

The writer regrets that he is not at present in a position to test and develop the method of research here proposed.

*H. M. Howe: "What is the essence of crystalhood?" Metallographist, (1902), 5, [1], 52.

THE RELATION BETWEEN THE CONSTITUTION OF A CLAY, AND ITS ABILITY TO TAKE A GOOD SALT GLAZE.

BY

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The subject of salt-glazing has received but little attention from investigators in ceramic work since its introduction by Flemish potters in the thirteenth century. Considering the extent to which the process is employed in the manufacture of clay products in this and other countries, and the fact that but little is known of the reactions of the process, and still less as to what materials are most suitable for such treatment, it is a matter of surprise that no attempts have been made to throw some light on this important branch of clay glazing.

In English ceramic literature the subject has received little or no consideration. The German writers have given some attention to the subject, but the bulk of the articles are either historical or deal with the actual practice in accomplishing the desired results.

The only article of real investigation which the writer has been able to find, is that on the action of iron in clay during salt-glazing, by Jos. Knett, published in Thonindustrie-Zeitung, 1896. Knett's experiments, while leading to highly interesting results, do not attack the truly fundamental principles of the process.

A desire to at least awaken a little interest, if possible, in original research along the line of salt-glazing, led the writer to make the investigations noted in this paper.

It is a well-known fact that some clays salt-glaze better than others, while some are not at all able to be glazed in this manner. Furthermore, the character of the glaze is different on different clays, as regards color, hardness and finish.

In order to draw a line if possible between salt-glazing and non-salt-glazing clays, it was decided to attack the subject by analysing both the clay and glaze from a factory where the work is successfully carried on, and from this basis vary the composition of the clay until its limit of ability to take a good glaze was reached. To this end, the clay used at Logan, Ohio, by the Hocking Clay Manufacturing Company, was selected. The salt-glazing done by this concern is of a high order, and their products are first-class representatives of salt-glazed clay wares. The process is here applied to bricks, sidewalk tiles, sewer pipe, garden urns, etc. The clay used is a fire clay of the Lower Kittanning horizon, the vein being pretty well weathered.

The methods used in securing samples of the clay and glaze for analysis were as follows:

SAMPLING THE BODY AND GLAZE.

In order to obtain a fair average sample of the clay as it entered into the product, a barrel was placed near the chute leading from the bin containing the screened clay from the dry pan, into the wet pan. Into this barrel the wet pan attendant threw a little of the ground screened clay at intervals, filling the barrel at the rate of about one-fifth each day. In this manner a fair average sample of the clay used in a five day's run was obtained. The contents of the barrel were then dumped onto a clean cement floor and thoroughly mixed, finally quartering down systematically until about thirty pounds remained. This was placed in an iron ball mill with flint pebbles, and ground fine. The finely ground clay was then spread on a table and mixed thoroughly, and then quartered down until a sample of a few hundred grams was obtained, which was bottled and labelled, and constituted the sample from which the analyses were made.

The glaze sample was obtained by chipping the salt-glaze from bricks taken at random from different stock piles, the only consideration being that the glaze should be sufficiently thick to chip off nicely. Bricks on which the glaze had run more or less towards one edge were chosen, and the glaze was carefully chipped off along this edge with a small cold

chisel and light hammer. About twenty grams of the glaze was secured in this way. From this, the sample for analysis was secured by selecting pieces of clear glass from the latter, rejecting any chips which showed any indication of adhering body. The chips of glaze thus selected were ground fine in an agate mortar, and weighed out for analysis.

ANALYSIS OF THE BODY AND GLAZE.

Two carefully made analyses of the clay gave the following results:

	No. 1	No. 2	Average
SiO_2	63.45	62.77	63.110
Al_2O_3	23.04	23.56	23.300
Fe_2O_3	2.03	2.44	2.235
CaO	.72	.73	.725
MgO	1.03	.91	.970
Na_2O	.53	.45	.490
K_2O	.93	.93	.930
SO_3	.24	.24	.240
H_2O	7.81	7.81	7.810
	99.78	99.84	99.810

Two analyses of the glaze gave:

	(a)	(b)	Average
SiO_2	55.60	55.35	55.475
Al_2O_3	21.14	21.54	21.340
Fe_2O_3	2.54	2.74	2.640
CaO	3.55	3.45	3.500
MgO	.04	.04	.040
Na_2O	16.91	17.51	17.210
K_2O	.08	.08	.080
	99.86	100.71	100.285

The glaze gives the following formula:

$$\left.\begin{matrix}.812\ Na_2O \\ .002\ K_2O \\ .182\ CaO \\ .002\ MgO \\ \hline .998\ RO\end{matrix}\right\} \left.\begin{matrix}.612\ Al_2O_3 \\ .048\ Fe_2O_3\end{matrix}\right\} 2.704\ SiO_2$$

The clay reduced to a formula becomes:

$$\left.\begin{matrix}.056\ CaO \\ .105\ MgO \\ .034\ Na_2O \\ .042\ K_2O\end{matrix}\right\} \left.\begin{matrix}1.00\ Al_2O_3 \\ .06\ Fe_2O_3\end{matrix}\right\} 4.605\ SiO_2\ (+1.957\ H_2O)$$

The glaze reduced to the same type of formula as the clay, viz., $Al_2O_3 = 1$, enables the following comparison to be made:

$$\text{(Clay)} \quad \left.\begin{matrix} .056\ CaO \\ .105\ MgO \\ .034\ Na_2O \\ .042\ K_2O \end{matrix}\right\} \; 1.00\ Al_2O_3 \left\{\begin{matrix} \\ .06\ Fe_2O_3 \end{matrix}\right. \left\{ 4.605\ SiO_2 \right.$$

$$\text{(Glaze)} \quad \left.\begin{matrix} 1.326\ Na_2O \\ .003\ K_2O \\ .297\ CaO \\ .003\ MgO \end{matrix}\right\} \; 1.00\ Al_2O_3 \left\{\begin{matrix} \\ .078\ Fe_2O_3 \end{matrix}\right. \left\{ 4.418\ SiO_2 \right.$$

It is seen that the silica is a little higher in the body than in the glaze, the alumina being the same. This is not to be regarded as strange, as the salt fumes cannot be expected to attack all the constituents of the clay with equal ease and incorporate them into a glass in exactly the same proportions as they exist in the clay. A certain per cent in the clay of coarse free sand which the salt does not easily attack, would no doubt lower the silica content of the glaze below that of the clay. Or, an aluminous coal-ash would tend to increase the proportion of Al_2O_3 to SiO_2 in the glaze over that in the clay, by being carried up into the kiln with salt vapors and lodging in the glaze.

A noticeable and interesting difference is in the amount of lime in body and glaze. While the clay shows only .725 percent of lime, the glaze shows 3.5 per cent. The most reasonable explanation for this difference seems to be that of efflorescence. The fact that this clay contains soluble sulphates, and is, moreover, known to efflorescence, might easily explain the presence of so much lime in the glaze. The soluble salts were brought to the surface and left there as a coating, long before the salt was applied to the fires. On salting the kiln, this efflorescence (mostly $CaSO_4$) was naturally absorbed as a part of the glaze.

While it is seen that the ratios of alumina to silica in clay and glaze are not exactly the same, still they are very close. From this we may reasonably infer that the ratio of alumina to silica in any clay which can be salt-glazed, is a good index of approximately what this ratio will be in the salt-glaze itself.

Langenbeck* holds that the molecular ratio of alumina to silica in a salt-glaze should be about 1 to 8, and assuming that a clay to be properly salt-glazed should contain alumina and silica in a similar ratio, he states that a clay best suited for salt-glazing will contain its alumina and silica in a molecular ratio of about 1 to 8.

This ratio of Langenbeck's is not borne out by the above analyses, nor by subsequent actual tests made by the writer. While it was found that a clay containing alumina and silica in the ratio of 1 to 8 would salt-glaze well, it was also found that the ratio could be much lower or much higher, and an equally good glaze could be obtained.

THE EXPERIMENTS PROJECTED.

To attain the object of this paper, namely, to throw some light on the relation between the constituents of a clay and its ability to be successfully salt-glazed, two series of experiments were first taken up, one decreasing the ratio of alumina to silica over that shown by the clay analysis, by additions of sand; the other increasing the ratio of alumina to silica, by additions of kaolin.

Starting with the Logan clay unadulterated, systematic additions of sand were made until a ratio of alumina to silica of 1 to 10 had been reached. This, it was thought, would show a point where the silica would be too high for a good salt-glaze.

This series is shown by the following table, in which the composition of the various mixtures proposed is indicated by their molecular formulæ:

SERIES I.

No.	KNaO	CaMgO	Al_2O_3	Fe_2O_3	SiO_2	Ratio Al_2O_3 to SiO_2	Remarks
8	.076	.161	1.00	0.06	4.60	1 : 4.6	
9	"	"	"	"	5.00	1 : 5.0	
10	"	"	"	"	6.00	1 : 6.0	
11	"	"	"	"	7.00	1 : 7.0	
12	"	"	"	"	8.00	1 : 8.0	
13	"	"	"	"	9.00	1 : 8.0	
14	"	"	"	"	10.00	1 : 10.0	

* Chemistry of Pottery, p. 90.

For increasing the ratio of alumina to silica, the Logan clay was treated with increasing additions of Florida kaolin. A series was made starting with the Logan clay unadulterated, (in which the ratio of alumina to silica is 1 to 4.6,) and ending with trials made wholly of kaolin, with a ratio of alumina to silica of 1 to 2. This series was as follows:

SERIES II.

No.	KNaO	CaMgO	Al_2O_3	Fe_2O_3	SiO_2	Ratio Al_2O_3 to SiO_2	Remarks
8	.076	.161	1.00	0.06	4.60	1 : 4.60	
7	"	"	2.00	"	6.60	1 : 3.30	
6	"	"	3.00	"	8.60	1 : 2.86	
5	"	"	4.00	"	10.60	1 : 2.65	
4	"	"	6.00	"	14.60	1 : 2.45	
3	"	"	10.00	"	22.60	1 : 2.26	
2	"	"	20.00	"	42.60	1 : 2.13	
1	"	"	1.00	"	2.00	1 : 2.00	

The complete test covered by the two series is shown in the following table:

No.	KNaO	CaMgO	Al_2O_3	Fe_2O_3	SiO_2	Ratio Al_2O_3 to SiO_2	Remarks
1	....	....	1.00	....	2.00	1 : 2.00	Florida kaolin
2	.076	.161	20.00	0.06	42.60	1 : 2.13	Obtained by mixing Florida kaolin and Logan F. C.
3	"	"	10.00	"	22.60	1 : 2.26	
4	"	"	6.00	"	14.60	1 : 2.45	
5	"	"	4.00	"	10.60	1 : 2.65	
6	"	"	3.00	"	8.60	1 : 2.86	
7	"	"	2.00	"	6.60	1 : 3.30	
8	.076	.161	1.00	0.06	4.60	1 : 4.60	Logan F. C.
9	"	"	"	"	5.00	1 : 5.00	Obtained by additions of Flint to Logan F. C.
10	"	"	"	"	6.00	1 : 6.00	
11	"	"	"	"	7.00	1 : 7.00	
12	"	"	"	"	8.00	1 : 8.00	
13	"	"	"	"	9.00	1 : 9.00	
14	"	"	"	"	10.00	1 : 10.00	

INGREDIENTS FOR THE SYNTHETIC CLAYS.

The sand used in the above mixtures was glass sand, of 40 to 60 mesh fineness.

A set of brickettes was also made running from 9a to 14a inclusive, using 150 to 200 mesh sand, but retaining the same mixtures as in the 9 to 14. A third set was also made from 9b to 14b, using sand which would not settle in twenty minutes in a standard sedimentation can in the university laboratory.

The finest sand, that which would not settle in twenty minutes, was obtained by vigorously stirring up commercial potters' flint with water in the standard sendimentation can.

This can was about twenty-six inches high and twelve inches in diameter, with a spout or tubulature one and one-fourth inches in diameter, placed six inches from the bottom.* After allowing the flint and water to stand twenty minutes, the liquid was let off through the spout. This was repeated until practically all of the sand which would not settle in twenty minutes was drawn off. The milky liquid thus obtained was allowed to stand for several days, after which the clear water was drawn off and the fine flint was obtained and dried.

The 40 to 60 mesh was obtained by taking glass sand and throwing same on a 40 mesh screen; all that went through was subsequently thrown on a 60 mesh sieve, and all that remained on the 60 mesh was reserved for use. That which went through 60 or did not go through 40 was rejected.

The 150 to 200 mesh was obtained by taking the sand rejected in the preceding process and grinding in a ball mill for two hours, then putting through a 150 mesh and then a 200 mesh sieve. All that went through the 150 mesh and lodged on the 200 mesh was reserved for use; that which went through 200 was rejected, and that which did not pass through 150 was reground.

The kaolinite used was a Florida kaolin, 98 per cent. pure kaolinite. This was passed through a 20 mesh screen before use.

The following table gives the proportion of each ingredient used in making the brickettes:

* See Trans. Am. Cer. Soc., Vol. II, p. 104.

No.	Logan Clay Grams	Kaolin Grams	Sand		
			40 to 60 mesh	150 to 200 mesh	Floated
1	0.0	800.0	.....	.....	.....
2	60.5	739.5	.....	.....	.....
3	118.0	682.0	.....	.....	.....
4	190.0	610.0	.....	.....	.....
5	273.0	527.0	.....	.....	.....
6	350.0	450.0	.....	.....	.....
7	487.0	313.0	.....	.....	.....
8	800.0	0.0	.....	.....	.....
9	755.0	.....	55.0	.....	.....
10	744.0	.....	156.0	.....	.....
11	662.5	.....	237.5	.....	.....
12	596.5	.....	303.5	.....	.....
13	543.0	.....	357.0	.....	.....
14	498.0	.....	402.0	.....	.....
9A	755.0	.....	.....	55.0	.....
10A	744.0	.....	.....	156.0	.....
11A	662.5	.....	.....	237.5	.....
12A	596.5	.....	.....	303.5	.....
13A	453.0	.....	.....	357.0	.....
14A	498.0	.....	.....	402.0	.....
9B	755.0	.....	.....	.....	55.0
10B	744.0	.....	.....	.....	156.0
11B	662.5	.....	.....	.....	237.5
12B	596.5	.....	.....	.....	303.5
13B	543.0	.....	.....	.....	357.0
14B	498.0	.....	.....	.....	402.0

PREPARING THE SAMPLES.

Two test brickettes were made from each mixture. These brickettes were made in a wooden mould 2½ x 4½ x 1 inches. The ingredients in each case were mixed thoroughly in a granite-ware pan, then made into a stiff mud with distilled water. The brickettes were dried in the laboratory by simply putting on pallets on shelves.

After drying the brickettes they were placed in No. 12 kiln of the Hocking Fire Clay Company, at Logan, Ohio. This is a round down draft kiln in which they regularly do salt-glazing. One brickette of each number was placed well to the top of the kiln, and one of each number put four inches above the floor. The kiln was burned and salted in the usual manner, and with results of ordinary attainment.

RESULTS OF BURN.

No. 8 brickettes, made from the Logan clay, took a nice smooth salt-glaze, deep brown in color, similar to the usual run of glazes obtained at this plant. This will be used as a basis of comparison.

Very little difference was noticed between the samples burned at the top and those burned at the bottom of the kiln. The results of the test were practically the same for both sets of brickettes, and were as follows:

The brickettes below No. 8 (those in which the ratio of alumina to silica was increased) deteriorated rapidly in the quality of the glaze. No. 7 was almost as good as No. 8, but the glaze was a little inferior in finish. Nos. 5 and 6 had a very poor dull glaze, greatly inferior to that of No. 8, and not at all entitled to be called a successful salt-glaze. No. 6 was a little better than No. 5. No. 4 had taken a dull reddish-brown gloss with insufficient thickness, glossiness or finish to be called a glaze. No. 3 had lost still further the resemblance to a glaze, and a dull red surface, slightly glossy in spots was all that the salt had accomplished. Nos. 1 and 2 had merely been colored a brick red, and showed no glaze whatever. No. 1 had the appearance of a red face brick, having assumed a fine red color very uniformly.

This red color shown by the unglazed brickettes is probably due to the volatilization of Fe_2Cl_6 and the subsequent deposition of Fe_2O_3, which occurs in salt-glazing, as shown by Knett,* and its entering afterwards into silicate formation with the clay. Occasionally red clouds of Fe_2Cl_6 appear at the beginning of the operation of salt-glazing a kiln, but soon cease. It is this Fe_2Cl_6 which is deposited on the ware as Fe_2O_3. The surface of the brickettes showing this color presented a beautiful mass of crystals under the glass.

Of the brickettes above No. 8 (those in which the ratio of alumina to silica was gradually diminished) all had taken a good salt-glaze. The following facts were noted:

* Thonindustrie-Zeitung (1896).

(*a*) As to brightness and smoothness, the brickettes from No. 8 up to No. 14 showed no deterioration, but on the other hand an improvement. No. 14 was a much brighter glaze than No. 8. In this respect the different finenesses of sand made no apparent difference, all finenesses for each number being equally bright and smooth.

(*b*) In color, the glazes grew much lighter as the sand content increased. Each brickette, from No. 8 up, was a little lighter than its predecessor. From No. 8, which was a deep brown, the color lightened to a stone gray in No. 14. A noticeable fact was that in the brickettes containing the finer sands, the lightening effect was increased. For instance, No. 11-A was as light as No. 14, and in the A series the color reached its lightest, being a fine clear gray in No. 14-A. In the B series No. 10-B was about the same shade as No. 11-A, and from No. 10-B the color grew lighter, but with a greenish tinge so that, while No. 14-B was very light it was a greenish gray and not a clear gray, as in No. 14-A.

(*c*) As to the crazing of the glazes, the following list gives the crazed and uncrazed glazes:

No.	Uncrazed	Crazed
8	8A 8B	....
9	9A 9B	.....
10	.....	10A 10B (slight)
11	.....	11A 11B
12	.....	12A 12B
13	.....	13A 13B } slight
14	.....	14A 14B }

As the foregoing series showed no deterioration of the salt-glaze with the increase of silica, contrary to what was expected, it was decided to still further increase the ratio of silica to alumina. For this purpose the following series was made:

SERIES III.

No.	KNaO	CaMgO	Al_2O_3	SiO_2	Ratio Al_2O_3 to SiO_2	Remarks
15	.076	.161	1.00	12.50	1 : 12.5	
16	"	"	"	15.00	1 : 15.0	
17	"	"	"	20.00	1 : 20.0	
18	"	"	"	40.00	1 : 40.0	
19	"	"	"	60.00	1 : 60.0	
20	0.0	0.0	0.0	100.00	all sand	

In view of the fact that in the previous test the fineness of sand made no apparent difference in the quality of the glaze the piece took; and also that samples in the bottom of the kiln showed no wide difference from those in the top, it was deemed sufficient to use merely one grade of sand in Series III, and to make only one set of brickettes. Accordingly, the fine floated silica was used, and one set of brickettes made as follows:

No.	Parts Logan Clay	Parts Sand
15	367	433
16	313	487
17	242	558
18	127	673
19	86	714
20	0	800

The brickettes were molded as those in Series I, except that owing to the extreme shortness of the mixtures, due to so much sand, it was necessary to use dextrine as a bonding agent to stick the material together and make brickettes which could be handled.

The brickettes were placed well to the top in one of the salt glazing kilns of the Hocking Clay Manufacturing Company, and burnt with a kiln of their ware. On drawing, the following results of the test were noted:

No. 15 was glazed but the glaze was thin, and in some places grew so thin as to be dull and rough. The glaze could not be called a good salt-glaze.

No. 16 showed glassy and smooth in places, but was mostly dull and rough, with insufficient glassiness to be called glazed.

No. 17 showed faint traces of glaze, but the greater part of the surface was dull, and while the salt had affected the entire surface, it had merely made a coating not unlike melted sugar in appearance. No. 17 presented a very interesting point, in that the brickette was well glazed on top but on none of the sides. No doubt, as the piece was exposed to flying ash and dust in the kiln, a certain amount of coal ash lodged on top of the brickette. This coal ash supplied the necessary alumina and the brickette the necessary silica to make a salt-glaze. The ash being unable to cling to the vertical sides of the brickette left these portions too silicious to make a glaze.

Nos. 18, 19 and 20 showed no traces of glaze whatever, and the salt had had no action on the pieces whatever. These brickettes had the same finish to their surface as when they entered the kiln, and very much resembled sand or bath bricks.

From Series I it was seen that a clay with an alumina-silica ratio of 1 to 10 gave a good salt-glaze. From Series III it was found that a clay with an alumina-silica ratio of 1 to 12.5 did not give a good salt-glaze. The limit lies between these two ratios, but lack of time prevented its exact determination. In view of this we shall have to assume temporarily that the limit was 1 to 12.5. This is more than likely, as the ratio of 1 to 10 gave a very good glaze, and the ratio of 1 to 12.5, while not a good glaze exactly, still it was not far over the line.

The following conclusions may now be safely drawn from the foregoing experiments in regard to the alumina-silica ratio.

1. A clay may be either too aluminous or too silicious to be successfully salt-glazed.

2. Clays containing alumina and silica between the molecular ratio of

1.00 alumina to 4.6 of silica
1.00 " " 12.5 "

are capable of receiving a salt-glaze if the process is properly carried out. If these limits are exceeded the material is not suited for salt-glazed ware.

3. While it is possible to salt-glaze clays containing alumina and silica in the above ratios, the requirements of the process of making stiff-mud goods would not permit the use of such silicious clays as those with an alumina-silica ratio of 1 to 9 or 1 to 10. That is, the practical value of a clay, as to plasticity, strength, etc., will draw narrower limits than those found in the above tests.

4. As regards brightness, smoothness and finish of the salt-glaze, it makes but little difference whether the free silica in the clay is fine or coarse.

5. As regards color, the finer the sand the lighter the color of the glaze. This has been substantiated in a practical way by Mr. A. Magoon, Superintendent of the Hocking Clay Manufacturing Co.

INFLUENCE OF EFFLORESCENCE.

Having come to some conclusion as to the limits of alumina and silica in a clay with reference to its receiving a good salt-glaze, it was decided to next look a little into the matter of efflorescence, or the presence of soluble salts in a clay and their bearing on the salt-glazing question.

Referring again to the difference in the lime contents of the Logan clay and the salt-glaze, as shown by the analyses, it is to be noted in this case that whatever efflorescence comes to the surface of the clay in burning did not interfere seriously with the clay taking a good glaze. The analysis of the glaze indicates that soluble salts were absorbed and became a part of the glaze.

Professor Orton * speaks of lime salts in paving brick interfering with their being salt-glazed, and many practical sewer-pipe burners will tell you of the troublesome "scum" which makes salt-glazing harder to accomplish.

The question now arises as to what extent the salt-vapors are able to attack efflorescence and secure the needed

* Ohio Geol. Survey, Vol. VII, Pt. I, p. 176.

alumina and silica from the clay beneath, and what amount of soluble salts in a clay will interfere seriously with salt glazing it.

In order to make an experiment in this direction some of the Logan fire clay was treated repeatedly with distilled water and finally with hot distilled water, the water being siphoned off after each treatment until it was judged that whatever soluble salts the clay contained had been dissolved out and drawn off in the water. The clay was then dried and ground, and put through a 20 mesh sieve. Starting with this clay soluble salts were added systematically up to three percent. The soluble salts added were calcium sulphate and magnesium sulphate in the proportion of three parts of the former to one of the latter.

The series was as follows:

SERIES IV.

No.	Logan Clay free from Soluble Salts	$CaSO_4$	$MgSO_4$	Per Cent. Soluble Salts
1-E	796	3.00	1.00	0.5
2-E	792	6.00	2.00	1.0
3-E	788	9.00	3.00	1.5
4-E	784	12.00	4.00	2.0
5-E	780	15.00	5.00	2.5
6-E	776	18.00	6.00	3.0

Two sets of these brickettes were made, one set was kept in the laboratory to dry, in order to note the appearance of efflorescence, if any, in drying. The other set was placed while damp in one of the Logan kilns, and burned.

The set of brickettes dried in the laboratory showed merely traces of efflorescence which did not increase with the amount of soluble salts contained in the clay.

The brickettes burned and salt-glazed all showed a good, smooth, deep brown glaze. The brightness of the glaze increased with the amount of soluble salts. The color of the glaze in each case was remarkable for its rich brown tone, being a deeper color than is usually obtained in the regular run of goods from these kilns.

Whether the soluble salts which had been added to the clay were brought to the surface in burning, is a question which cannot be decided with the data at hand. The set put in the laboratory to dry, however, showed that the efflorescence did not come out to any extent in drying.

The effect of efflorescence therefore is still a matter to be decided. That enough calcium sulphate can exist on the surface of a brick to prevent its taking a good salt glaze under standard conditions, the writer has demonstrated by heavily coating a number of green bricks at the Logan factory with plaster of paris mixed with water, and placing same in different parts of the kiln. The surfaces which were treated in this manner came out slightly glazed, but with a dull yellowish, unsightly color.

SALT GLAZE CONSIDERED AS A GLASS.

Knett gives the following as the reactions which occur in salt-glazing:

$$(Al\ Fe)_2O_3 \times SiO_2 + 6\ Na\ Cl = (Al\ Na_3)_2O_3 \times SiO_2 + Fe_2Cl_6$$
$$Fe_2Cl_6 + 3\ H_2O = Fe_2O_3 + 6\ H\ Cl$$

According to this, the ratio of soda to alumina in the glaze would be

$$3\ Na_2O : Al_2O_3$$

Langenbeck * says, "Such glazes (salt-glazes) approximate a formula:

$$1\ RO,\ .5\ R_2O_3,\ 4.\ SiO_2$$

By referring to formula III, deduced from the actual analysis of the Logan salt-glaze, namely:

$$\left.\begin{matrix}1.326\ Na_2O\\ .003\ K_2O\\ .297\ CaO\\ .003\ MgO\end{matrix}\right\}\ \left.\begin{matrix}1.000\ Al_2O_3\\ .078\ Fe_2O_3\end{matrix}\right\}\ 4.418\ SiO_2$$

It is readily seen that both Knett and Langenbeck place the ratio of alumina to soda much lower than that found by the writer to actually exist in the glaze.

In order to prove the feasibility of glasses high in alumina, it was decided to make up a series of glasses to substantiate the glaze formula found by analysis.

*Chemistry of Pottery.

In a series of glass experiments Professor Orton * demonstrates that a glass of the following composition:

$$\left.\begin{matrix}.5\ Na_2O \\ .5\ CaO\end{matrix}\right\} 0.20\ Al_2O_3,\ 0.80\ SiO_2 \qquad \text{Oxygen Ratio } 1:1$$

was much more fusible at cone 8 than a glass of the composition:

$$\left.\begin{matrix}.5\ Na_2O \\ .5\ CaO\end{matrix}\right\} 0.0\ Al_2O_3,\ 0.50\ SiO_2 \qquad \text{Oxygen Ratio } 1:1$$

Starting with the glass given in the above formula, it was decided to not merely increase the alumina as Professor Orton had done, but to replace the lime with alumina in order to approach the salt-glaze formula, which is practically:

$$\left.\begin{matrix}.8\ Na_2O \\ .2\ CaO\end{matrix}\right\} 0.6\ Al_2O_3,\ 2.70\ SiO_2 \qquad \text{Oxygen Ratio } 1:1.93$$

To this end the following series of glasses was made up:

SERIES V.

No.	Na_2O	CaO	Al_2O_3	SiO_2
1	0.5	0.5	0.0	0.5
2	0.5	0.4	0.033	0.5
3	0.5	0.3	0.066	0.5
4	0.5	0 2	0.100	0.5
5	0.5	0.1	0.133	0.5
6	0.5	0.0	0.166	0.5

In this series the oxygen ratio was kept constant, namely, 1 : 1.

These glass mixtures were placed in porcelain cups and fired in a test kiln to cone No. 8. On cooling and drawing the kiln the following results were noted:

(*a*) No. 1 was a stony mass, resembling blast furnace slag.

(*b*) Nos. 2 to 6, inclusive, were all good glasses, well melted.

(*c*) No. 5 was a little better glass than No. 6, showing lime had helped the mixture to some extent.

(*d*) No. 5 was as good, if not a little better than any of the other glasses.

* Trans. Am. Cer. Soc., Vol. IV.

Taking the formula for No. 5 glass, namely:

$$\left.\begin{matrix}.5\ Na_2O \\ .1\ CaO\end{matrix}\right\} .133\ Al_2O_3,\ \ 0.50\ SiO_2$$

and reducing this to a basis of RO = 1, we obtain

$$\left.\begin{matrix}.83\ Na_2O \\ .17\ CaO\end{matrix}\right\} .221\ Al_2O_3,\ \ .83\ SiO_2$$

It will be seen that the RO contents here are very close indeed to the RO contents of the Logan salt-glaze.

Having proved that a soda-alumina glass is fully as feasible as a soda-lime glass, and having obtained in the No. 5 glass an RO content practically the same as in the salt-glaze, a series was next prepared, increasing the alumina and silica contents of No. 5 glass and also the oxygen ratio, until the formula for the salt-glaze was obtained.

The series for this purpose was as follows:

SERIES VI.

Number	Na_2O	CaO	Al_2O_3	SiO_2	RO	Remarks
7	0.80	0.20	0.221	.83	1 : 1.00	
8	"	"	0.360	1.30	1 : 1.25	
9	"	"	0.440	1.76	1 : 1.50	
10	"	"	0.510	2.23	1 : 1.75	
11	"	"	0.600	2.70	1 : 1.93	Logan Salt-Glaze

This series was treated as the preceding, being melted in porcelain cups at cone No. 8.

On cooling and drawing the following results were noted:

(*a*) All had melted to glasses.

(*b*) Nos. 7, 8, 9 and 10 had melted into solid cakes of glass, showing very little difference.

(*c*) Nos. 7 and 8 showed no bubbles in the glass. No. 9 showed a number of small bubbles through the glass mass, and No. 10 showed larger bubbles. But these were still very good glasses.

(*d*) No. 10 while a glassy mass, very much the same in color as the Logan salt-glaze, was very spongy throughout. The mass, however, was a good, sharp, well melted glass, which, if ground up and applied to a brick surface, would

undoubtedly flow to a glaze very similar to the salt-glaze. The bubbling was merely due to insufficient time in melting to allow the carbon gases to completely escape.

By the foregoing glass experiments it has been clearly demonstrated.

First. That in a soda-lime glass similar to that shown by No. I, Series V, alumina may replace the lime in part or even completely, and a good glass will still be obtained. In other words, soda-alumina glass is as feasible as a soda-lime glass at the same heat.

Second. That a little lime in a glass mixture of this type makes a little better glass than with no lime.

Third. That a soda-lime alumina glass can be made at cone No. 8 with a wide range of alumina and silica. Glassy masses are obtained with mixtures in which the alumina and silica runs from 0.221 Al_2O_3, 0.83 SiO_2 to 0.600 Al_2O_3, 2.70 SiO_2.

Fourth. That by compounding a mixture corresponding to the formula deduced from the analysis of the salt-glaze, a a glass is obtained at salt-glazing temperature (cone No. 8), very similar in all respects to the salt-glaze actually obtained in commercial work. The analysis of the salt-glaze and the subsequent compounding of a glass from this analysis therefore harmonize perfectly.

SUMMARY.

In the above paper, we have obtained the analysis and formulæ for both the clay and glaze actually used in successful salt-glazing work. From the experiments it was found that clays with a wide molecular ratio of alumina to silica could be salt-glazed, viz.: from 1 : 4.6 to 1 : 12.5. Also, from the glass tests, we found that glasses could be made with a generous variation of alumina and silica. Connecting these observations, it is reasonable to suppose that the salt-glaze on the different clays varied in composition according to the clay composition. For instance, in the Logan clay and glaze, the ratio of alumina to silica is very close. Now when the ratio in the clay had been changed, is it not probable that the composition of the glaze formed changed, also ?

This can only be determined by actually analysing the salt-glaze formed on different bodies of known composition.

By the efflorescence test it was demonstrated that up to three per cent. of soluble salts may be present in clay without seriously interfering with salt-glazing when conducted at cone No. 8. Whether or not, however, all the added salts came to the surface was not determined.

It would be an interesting point for other investigators in this line, to determine the effect of sulphurous gases on salt-glazes. This could be done by treating a piece of salt-glazed ware with sulphur gases in a closed tube. That the action of sulphur has an important bearing on the quality of the salt-glaze seems highly probable. It would be of interest and value to also determine the temperature at which glazing begins, and whether it can be overdone by high heat. Also to ascertain the relation of the temperatures of salt-glazing red-burning clays and buff-burning clays, and what effect $CaSO_4$ or other soluble salts has on the glazing of red-burning clays. Furthermore, whether steam aids the process or not is still a questionable point.

The writer regrets that the time set apart for this work on salt-glazing did not permit of his looking into the last mentioned points, but hopes that they will be investigated before long.

In conclusion, the writer desires to thank especially Mr. A. Magoon, of the Hocking Clay Manufacturing Company, who generously took the time and trouble to furnish samples of his clay and glaze, and to take care of the burning of the experimental trials.

THE CONSTITUTION OF CHROMIUM-TIN PINK.

BY

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The subject of the chromium-tin colors offers a field for investigation to which, considering the extent to which the colors are used in ceramic work, but little attention has been paid. Most of the published information on the subject we owe to Leykauf and Seger. The former studied the compounds of chromium and tin from a purely chemical standpoint, while Dr. Seger has given receipts and directions for the production of ceramic colors by the use of these materials.

REVIEW OF PREVIOUS INVESTIGATIONS.

Leykauf concluded from his investigations, (Jour. Soc. Chem. Ind., 1892) that chromium stannate can be obtained by igniting stannic chromate at a high temperature, and forms a dark violet mass, from which glazes varying in color from rose-red to dark violet can be prepared. He found that when chromic oxide and stannic oxide were ignited together in the proportion of one of the former to fifty of the latter, that a mass composed of a mixture of fine crystals and fused, glassy particles of a beautiful permanent lilac color were obtained. According to Leykauf, "pink color" consists of this substance, mixed with calcium stannate.

Leykauf's statement that "pink color" contains chromic stannate was contradicted by Petrik, who found that a pink coloring body could be produced as well by the aid of alumina or a mixture of alumina and magnesia, as by means of tin oxide. He used for the purpose the precipitated hydroxides obtained from 90.6 g. ammonia alum, and 24.6 g. magnesium sulphate, which were ground together with .5 g. potassium chromate. The mass was burned twice, being well washed after the first burning. During the second burning the red color appeared. In the presence of a larger amount of chromic oxide, only a green color resulted. An increase in the amount of magnesia favored the formation of the red color, while the substitution of lime, baryta or strontia for magnesia

seemed to have a contrary effect. Petrik thought that this was the case because the precipitated alumina was coarser, and that, in all probability, the chromium color compound only appears pink when very finely divided. From this investigation, Petrik concluded that the "pink color" does not contain chromic stannate, but that a red chromium compound, apparently chromic oxide in a finely divided state, is precipitated upon the stannic acid serving as a "base."

The investigations of Leykauf and Petrik are of considerable interest, but the hypotheses which they offered in explanation of the formation of the color are evidently contradictory, and the facts produced in each case were insufficient to establish any theory.

If we lay aside the theoretical considerations and look for the useful facts which have been published on the subject, we find them stated briefly in Seger's discussion of underglaze colors, as follows:

"Chromium oxide with tin oxide and lime produces red tints. The red colors show many peculiarities which must be considered. They are obtained, when to a mixture of marble and tin oxide a small addition of potassium chromate is made, and the mixture strongly ignited. Outside of the potassium chromate, quite a number of substances produce the same effect, but it is safest to work with potassium chromate. However, if too much of the latter is used, (over 3 to 4 per cent,) the resisting power of the underglaze color is reduced considerably. If silica is added to the mixture the color turns toward red, if the lime is decreased, toward lilac, and excluding the latter from the composition entirely, it becomes a pure lilac color. A very strong fire is necessary. The red colors require oxidizing conditions, and are destroyed by reduction but renewed on continued oxidation."

In addition to this general discussion, Seger gives, with directions for their preparation, the following receipts:

Pink-Red.

	Parts
Pure ignited tin oxide	50
Marble	25
Quartz	18
Acid potassium chromate	3
Borax	4
	100

This fritt, after ignition, would have the following formula:

$$\left.\begin{matrix}.924\ CaO\\ .038\ K_2O\\ .038\ Na_2O\end{matrix}\right\} .038\ Cr_2O_3 \left\{\begin{matrix}1.109\ SiO_2\\ 0.076\ B_2O_3\\ 1.238\ SnO_2\end{matrix}\right.$$

Reddish-Blue.

	Parts
Ignited tin oxide	70
Marble	23
Acid potassium chromate	3
Borax	4

This fritt, after ignition, would have the following formula:

$$\left.\begin{matrix}.918\ CaO\\ .0406\ K_2O\\ .0414\ Na_2O\end{matrix}\right\} .0406\ Cr_2O_3 \left\{\begin{matrix}.0828\ B_2O_3\\ 1.875\ SnO_2\end{matrix}\right.$$

By leaving out the marble, a lilac is obtained which is suitable for white ware, but cannot resist a high heat like that of the porcelain kiln.

Lilac.

	Parts
Ignited tin oxide	50
Potassium bichromate	3
Borax	20

of which the formula would be:

$$\left.\begin{matrix}.163\ K_2O\\ .837\ Na_2O\end{matrix}\right\} .163\ Cr_2O_3 \left\{\begin{matrix}1.674\ B_2O_3\\ 5.36\ SnO_2\end{matrix}\right.$$

The first of these receipts is used by many potters, not only as an underglaze color, but also in majolica glazes. However, in some cases considerable difficulty is experienced in using it, owing to the fact that the glazes destroy the color. An example of this sort of difficulty, and the manner in which it was overcome, is found in the paper by Mayer, in the Transactions of the American Ceramic Society, Vol. I. Mr. Mayer's experiments proved conclusively that in his case the trouble was caused by the glaze, and that another glaze could be used, which, under the same conditions, did not destroy the underglaze color. Why one glaze destroyed the color and another did not, has not been determined.

SCOPE OF THIS INVESTIGATION.

The experiments described below were made for the purpose of adding something to the available information upon the following phases of this subject: *First.* The most

favorable composition for the pink fritt. *Second*, The type of low fire glaze which develops the color to the best advantage.

THE MOST FAVORABLE COMPOSITION OF THE PINK FRITT.

The work done on the first phase of the subject, consisted of making three series of fritts, beginning with a series of combinations of chromic oxide and stannic oxide alone. Taking the members of this series which had the highest allowable ratio of chromic oxide to stannic oxide, a second series was made, keeping this chrome-tin ratio constant, and adding an increased proportion of lime. Finally, the best member of the chrome-tin-lime series was taken as a basis for a third series, in which silica was added in regularly increasing proportions.

In these series, the tin was supplied by SnO_2, the chromium by CrO_3 and the lime by $CaCO_3$. These materials were all chemically pure, but for the silica, Golding flint was used. The SnO_2, $CaCO_3$ and SiO_2 were all fine enough to make further grinding unnecessary, the coarsest leaving about 3 per cent. on an 80 mesh screen. In making the mixtures, the insoluble ingredients for each fritt were weighed dry, and placed in a caserole. The CrO_3 was added from a burette, a standard solution being used. Sufficient water was then added to make the mass into a thin paste, which was thoroughly stirred and then dried on a water bath, the stirring being repeated at frequent intervals to insure an intimate mixture of the ingredients. Each mixture was then placed in an air bath to complete the drying, and finally each was thoroughly ground in an agate mortar. Owing to the fineness of the materials used, it was possible to secure a good fine mixture with a reasonable amount of grinding, and it is thought that by adding CrO_3 in solution, a better contact of the particles was secured than could have been done by a dry process of mixing.

The fritts were calcined in a small gas furnace, fired by means of a blast lamp. The furnace consists of a vertical hollow cylinder of fire clay, the inside diameter being about five inches and the height six inches. The blast lamp flame

enters horizontally at the bottom of the furnace. The cylinder is covered with a fire clay disc, in the center of which is an inch hole which serves the double purpose of a peep hole and gas outlet. With this furnace we were able to reach cone 18 with oxidizing conditions. The fritts, about 30 g. each, were calcined in small fire-clay crucibles without lids. Each member of the first two series was fired for forty-five minutes, at about cone 16. The third series was kept at cone 8 to 10 for an hour.

The following table shows the composition of the members of the first series:

SERIES A-I.

No. of Fritt	Composition by Weight		Equivalents.	
	Parts of SnO_2	Parts of CrO_3	SnO_2	Cr_2O_3
1	50	1	1	.015
2	40	1	1	.0185
3	30	1	1	.025
4	20	1	1	.0375
5	15	1	1	.050
6	10	1	1	.075
7	5	1	1	.150
8	2.5	1	1	.300

The appearance of the fritts of the first series, after calcination, were as follows:

Each fritt was in a soft friable mass, none of them having formed a hard cake. The color of the first four was a rich purple, nearly as strong in one as in the other. Beginning with No. 4, there came a regular gradation of color, ranging from a rich purple to the green of Cr_2O_3. This showed that with these conditions the maximum allowable molecular ratio of Cr_2O_3 to SnO_2 was .0375 : 1. Above this ratio the excess of SnO_2 was not great enough to prevent the existence of free Cr_2O_3.

No. 4 of this series was allowed to cool very slowly in order to favor the formation of crystals, and was then examined microscopically. The microscope revealed isolated white particles and colored masses, which showed no distinct granular or crystalline particles. When viewed through crossed Nicol's prisms, no evidence of crystallization could

be detected. This does not correspond to the description given by Leykauf. It is true that the white particles looked like crystals, but they failed to show any evidence of polarization.

For the second series, the ratio of SnO_2 to CrO_3 was maintained the same as that in No. 4 of the first series, and the lime was increased as shown in the following table:

SERIES A-II.

No. of Fritt	Percents by Weight		Molecular Proportions		
	Fritt No. 4	$CaCO_3$	SnO_2	CaO	Cr_2O_3
9	100	0	1	.0	.0375
10	80	20	1	.391	.0375
11	60	40	1	1.04	.0375
12	40	60	1	2.34	.0375
13	20	80	1	6.25	.0375

The effect of the lime upon the chrome-tin fritt was very marked. No. 10 was a reddish-brown, while No. 11 was a stronger, deeper brown. The higher numbers became glassy, and the color took on a greenish cast, which predominated in the highest numbers. No. 13 melted to a green glass, which attacked the crucible strongly.

Taking the chrome-tin-lime ratio of 11, the effect of SiO_2 was then tried by the following series:

SERIES A-III.

No. of Fritt	Molecular Proportions			
	SnO_2	$CaCO_3$	SiO_2	Cr_2O_3
14	1	1	.0	.0375
15	1	1	.5	.0375
16	1	1	1.0	.0375
17	1	1	1.5	.0375
18	1	1	2.0	.0375

In this series the colors ranged from a strong brown in No. 14 to a strong pink in No. 18. The difference in shade between Nos. 16, 17 and 18 was, however, very slight, and any of these would pass for a good pink fritt.

It would require a much more extended investigation than this to determine to what extent the proportions of these fritt ingredients could be varied, and a good fritt be obtained. The following consideration made it seem desirable to use, in the glazes to be tried, a formula not differing widely from that of the upper numbers of Series A-III:

1. The tin might be raised without detriment to the fritt itself, but it is not considered desirable to introduce more tin than is necessary into soft fire glazes. It may be that the tin could be decreased, but the results of these experiments do not indicate that this could be done to any considerable extent.

2. Series A-I indicates that the quantity of chromic oxide is as high as is allowable.

3. The lime was purposely made as high as Series A-II would warrant.

4. This fritt corresponded closely, both in appearance and in composition to the pink fritt recommended by Seger, except that the tin is lower in the fritts of Series A-III. Seger's fritt, however, was intended for an underglaze color for porcelain, and in that case a high excess of tin in the fritt would not be detrimental to the glaze.

THE EFFECT OF LEAD AND BORACIC ACID UPON THE CHROMIUM–TIN PINK IN LOW FIRE GLAZES.

As has been stated, it was desired to determine what type of low fire glaze is most favorable for the development of the pink color. In planning this investigation, the following facts were to be taken into consideration:

1. Too high a lead content in the glaze is detrimental to the color. Professor Orton, in one of his lectures on the subject of colored glazes, states that in a chromium-tin pink glaze not more than .45 equivalents of lead is permissible. Moreover, preliminary tests of my own with a glaze containing .6 equivalents of lead failed to produce a pink glaze at all.

2. Seger states that boracic acid in the fritt changes the color toward purple, and it was expected that boracic acid in the glaze would produce the same effect to some extent.

In view of these facts the problem seemed to resolve itself into the following phases: *First*, To determine the permissible content of lead. *Second*, To find how much B_2O_3 is allowable. *Third*, To design a glaze maturing at cone 02 or 01, in which these limits of composition are not exceeded.

The first thing which was attempted in this connection was to determine the effect of increasing the content of boracic acid in a glaze containing lead. The glaze selected for this purpose had the following formula:

$$\left.\begin{matrix}0.25\ PbO\\0.25\ KNaO\\0.50\ CaO\end{matrix}\right\}\ 0.2\ Al_2O_3,\ 2.00\ SiO_2\ \left\{\begin{matrix}0.005\ Cr_2O_3\\0.185\ SnO_2\end{matrix}\right.$$

It was thought that .25 equivalents of lead was not sufficient to be detrimental to the color, and that quantity was accordingly used to help in softening the glaze.

The boracic acid was introduced into the glaze by the use of a fritt of the following composition:

$$\left.\begin{matrix}0.5\ Na_2O\\0.5\ CaO\end{matrix}\right\}\ 0.054\ Al_2O_3\ \left\{\begin{matrix}2.29\ SiO_2\\1.19\ B_2O_3\end{matrix}\right.$$

The pink fritt used in this series was the underglaze pink recommend by Seger:

$$\left.\begin{matrix}0.924\ CaO\\0.038\ K_2O\\0.038\ Na_2O\end{matrix}\right\}\begin{matrix}1.109\ SiO_2\\0.076\ B_2O_3\end{matrix}\ \left\{\begin{matrix}1.238\ SnO_2\\0.038\ Cr_2O_3\end{matrix}\right.$$

The composition of the glazes of this series is shown by the following table:

SERIES B.

No.	PbO	KNaO	CaO	Al_2O_3	SiO_2	B_2O_3	Cr_2O_3	SnO_2
1	.25	.25	.50	.2	2.00	.35	.005	.185
2	.25	.25	.50	.2	2.00	.40	.005	.185
3	.25	.25	.50	.2	2.00	.45	.005	.185
4	.25	.25	.50	.2	2.00	.50	.005	.185

It will be seen that the boracic acid varies between somewhat narrow limits in this case, but the range proved to be wide enough for the purpose.

The method of preparation of these glazes and of all those which will be discussed, was as follows:

The batches for the first and last glaze of each series were weighed out and ground wet in porcelain ball mills. After grinding, the glaze batches were screened through a 150 mesh screen. As most of the materials were finely ground to start with, two or three hours of grinding were sufficient in all cases, to make the glaze slip go through the 150 mesh sieve like so much water. After screening, the slip was allowed to settle and the supernatant water syphoned off as closely as possible. A sample of each slip was then taken and the quantity of dry material per unit of slip determined. This completed the data necessary to calculate the proportions in which the two slips would have to be blended to produce the intermediate numbers of the series.

The manner of the preparation of the fritts, except in the case of the pink fritts, for which a description has already been given, was to grind the fritt batch dry to secure a good mixture, and melt it in a large Hessian crucible in the gas furnace already described. The fritt when melted, was poured from the crucible into cold water, replacing and refilling the crucible and repeating the operation as many times as necessary. Fritts could be poured in this way which would not readily run through an opening in the bottom of the crucible. After being crackled in this way, a fritt would be ground wet in a glaze mill, screened through 150 mesh sieve, allowed to settle and the water syphoned off. The fritt was then dried ready for weighing.

The burning, unless otherwise stated, was done in a down-draft test kiln. With this kiln it was possible to get a fairly uniform distribution of the heat and to make as good a burn as can be expected with a test kiln having but one furnace. Of course, there were short periods of reduction, when fresh fuel was added, but this by careful firing could be kept from going too far. Coke was used for fuel in each burn until a red heat was reached. At that stage the use of coal was commenced. However, no fresh coal was thrown upon the grate bars, but was placed upon the coking plate just inside the furnace door and kept there till most of the volatile part of the fuel was roasted out before spreading

over the bars. In this way the condition of the kiln gases was kept fairly uniform.

The glazes were all applied to white tiles, 4½ inches long by 1 inch in width and set in saggers, which were then covered and luted tight.

The trials of series B were set on end in a large sagger and placed near the top of the kiln. Cones were placed in front of the sagger in a smaller sagger placed on its side. In burning, the heat was raised as rapidly as it could be and still keep the predominating conditions of the kiln strongly oxidizing. Cone 04 was reached in eleven hours. The heat was brought up more slowly during the next hour and the firing discontinued at the end of the twelfth hour, with cone 02 down in the front sagger, 01 having been reached in the sagger with the trials.

In the resulting glazes, the effect of the boracic acid was apparent. As was expected, the boracic acid softened the glaze, but also seemed detrimental to the color.

The appearance of the individual pieces was as follows:

Glaze B-1.

B_2O_3=.35—This glaze was somewhat immature and showed a tendency to bead up, leaving patches of bare surface on the tile. Slight tendency to flow. The color was a deep, strong maroon.

Glaze B-2.

B_2O_3=.40—Glaze fairly well matured, with some tendency to flow. Glaze would pass aside from color. Color, slightly inferior to B–1, there being some white flocky segregrations which are detrimental. Shade nearly the same as that of B–1.

Glaze B–3.

B_2O_3=.45—This is a good nature glaze but its appearance is bad. The flocky segregations, apparently due to tin, predominate.

Glaze B–4.

B_2O_3=.50—In this glaze the pink is almost entirely destroyed and the tin-enamel effect is solid instead of flocky.

It is evident that in this glaze, the use of more than .4 equivalents of boracic acid is not permissible. It is also evident that, under the conditions, at least .4 B_2O_3 is required in order that the glaze will mature. Moreover, the color is not bright enough to be satisfactory in any of the pieces.

The only definite conclusion that can be drawn from this series is that this particular glaze, (B–1) does not develop a good pink color when softened with sufficient B_2O_3 to make it mature under the conditions described at cone 0I.

In order to determine more definitely the effect of different equivalents of PbO and B_2O_3 upon the color, three series of glazes were made, being so designed as to keep the acid ratio and the alumina content constant throughout. In one case, SiO_2 alone was used for the acid, and in the RO group the ratio of KNaO to CaO was kept approximately 1 : 2, while the content of PbO increased regularly by additions of .2 equivalents. In the other series the RO group was maintained constant, while the SiO_2 was replaced by successive additions of .2 equivalents of B_2O_3. Finally a series was made in which the acid ratio was kept constant, but the PbO was made to decrease, while the B_2O_3 increased. The extremes for these series were as follows:

1. A fritted soda-lime glaze free from both PbO and B_2O_3:

$$\left.\begin{matrix}0.33\ KNaO\\0.67\ CaO\end{matrix}\right\}\ 2.00\ Al_2O_3,\ \ .2\ SiO_2\ \left\{\begin{matrix}0.005\ Cr_2O_3\\0.144\ SiO_2\end{matrix}\right.$$

In making this glaze, a fritt of the following composition was used, obviating the use of much raw material, and thereby softening the glaze considerably:

$$\left.\begin{matrix}0.33\ KNaO\\0.67\ CaO\end{matrix}\right\}\ 0.13\ Al_2O_3,\ 1.00\ SiO_2$$

2. A raw lead glaze without B_2O_3:

$$\left.\begin{matrix}0.851\ PbO\\0.011\ KNaO\\0.138\ CaO\end{matrix}\right\}\ 0.2\ Al_2O_3,\ 2.00\ SiO_2\ \left\{\begin{matrix}0.005\ Cr_2O_3\\0.144\ SnO_2\end{matrix}\right.$$

In this glaze, the CaO and KNaO were only such as were necessarily brought in by the pink fritt.

3 A fritted boracic acid glaze without lead:

$$\left.\begin{matrix}0.33\ KNaO\\0.67\ CaO\end{matrix}\right\}0.2\ Al_2O_3\left\{\begin{matrix}1.00\ SiO_2\\1.00\ B_2O_3\end{matrix}\right\}\begin{matrix}0.005\ Cr_2O_3\\0.144\ SnO_2\end{matrix}$$

In the batch for the glaze the amount of raw material was reduced to .05 equivalents of clay, by using the following fritt:

$$\left.\begin{matrix}0.373\ KNaO\\0.622\ CaO\end{matrix}\right\}0.176\ Al_2O_3\left\{\begin{matrix}.858\ SiO_2\\1.170\ B_2O_3\end{matrix}\right.$$

In these three series a pink fritt of the following composition was used:

$$\left.\begin{matrix}0.924\ CaO\\1.109\ SiO_2\\0.038\ K_2O\\0.076\ B_2O_3\\0.038\ Na_2O\end{matrix}\right\}\begin{matrix}1.238\ SnO_2\\0.038\ Cr_2O_3\end{matrix}$$

The following tables contain the formulæ of the glazes obtained by blending the extremes:

SERIES C.

No.	PbO	KNaO	CaO	Al_2O_3	SiO_2	Cr_2O_3	SnO_2
1	.000	.330	.670	.2	2.0	.005	.144
2	.200	.254	.544	.2	2.0	.005	.144
3	.400	.180	.420	.2	2.0	.005	.144
4	.600	.105	.294	.2	2.0	.005	.144
5	.851	.011	.138	.2	2.0	.005	.144

SERIES D.

No.	KNaO	CaO	Al_2O_3	SiO_2	B_2O_3	Cr_2O_3	SnO_2
1	.33	.67	.2	2.0	0.0	.005	.144
2	.33	.67	.2	1.8	0.2	.005	.144
3	.33	.67	.2	1.6	0.4	.005	.144
4	.33	.67	.2	1.4	0.6	.005	.144
5	.33	.67	.2	1.2	0.8	.005	.144
6	.33	.67	.2	1.0	1.0	.005	.144

SERIES E.

No.	PbO	KNaO	CaO	Al_2O_3	SiO_2	B_2O_3	Cr_2O_3	SnO_2
1	.851	.011	.138	.2	2.0	0.0	.005	.144
2	.681	.075	.244	.2	1.8	0.2	.005	.144
3	.511	.139	.350	.2	1.6	0.4	.005	.144
4	.340	.203	.456	.2	1.4	0.6	.005	.144
5	.170	.266	.563	.2	1.2	0.8	.005	.144
6	.000	.330	.670	.2	1.0	1.0	.005	.144

The glazes of these series were prepared, dipped, set and burned as described for series B.

The results obtained, while they failed to give the color that was desired, demonstrated unmistakably the effects of lead and boracic acid in the glaze.

Series C showed a regular gradation from a fairly good pink color in C–1 to a glaze in C–5, in which there was no resemblance whatever to a pink color. Individually, the glazes were as follows:

Glaze C–1.

PbO=0—Glaze immature. Color pink, but dull, owing to immaturity of glaze. This same glaze when fired to cone 3, gave a good clear pink.

Glaze C–2.

PbO=.2—Very bright and pretty pink enamel over greater portion of surface, surrounded by a border of white enamel. The glaze is somewhat immature. The same glaze was burned at cone 3 and though over-burned, gave a strong pink color with a fringe of white.

Glaze C–3.

Pbo=.4—Strangely enough, this number shows more of a tendency to bead up and have bare spots on the surface of the tile. The appearance is that of an immature enamel, fringed with white, with a flush of pinkish brown over the remainder of the surface. The shade is much darker than in C–2.

Glaze C–4.

PbO=.6—A gray opaque enamel, beaded to some extent. It is found by breaking the piece so as to show it in cross-section, that this enamel is mature only at the surface, beneath which the color is not destroyed.

Glaze C–5.

PbO=.851—Very ugly enamel with a tinge of green. From this series it is evident in the first place that none of the glazes will mature at cone 01 with the sort of burn described; and in the next place that for this glaze the upper limit of PbO lies somewhere between .2 and .4 equivalents. In this series, as also in the one preceding it, the

quantity of pink fritt was too great. The colors, where not destroyed, were unnecessarily strong, the glazes too opaque, and naturally more flux was required to produce a mature glaze than would be necessary if less of the pink fritt were used. It is thought that C–2 and C–3 would be considerably improved by using only enough pink fritt to introduce .003 instead of .005 equivalents of Cr_2O_3.

In Series D we have the effects of B_2O_3 even more clearly demonstrated. The glazes change progressively from immature pinks in D–1 through a series of mature purplish pinks, to a dark purple glaze, which is very immature at the other extreme.

Glaze D–1.

Same as C–1.

Glaze D–2.

B_2O_3=.2—This glaze is somewhat immature. The color though not fully developed, is a deep strong maroon. The same glaze fired to cone 3 resulted in a good smooth glaze with a strong pink color, slightly tinted with purple.

Glaze D–3.

B_2O_3=.4—This glaze is badly scummed but is perfect in other respects. The color is a strong dark pink with a marked purplish tint.

Glaze D–4.

B_2O_3=.6—Glaze not quite mature. In appearance very bad. It has a mottled effect produced by flocky seggregations of a pale purple color, replacing the pink. In this glaze the B_2O_3 is evidently too high.

The next two numbers, D–5 and D–6, are both far beyond the limit. Both are immature, and a very dark purple in color.

D–3 is by far the best number in this series. On one side of D–3 in the series, the lower limit of B_2O_3 is marked by D–2 with .2 B_2O_3, while on the other side the upper limit is passed before D–4 with .6 B_2O_3 is reached.

This series leads us to the following conclusions:

1. That B_2O_3 gives a purple tint to the pink color.
2. That in this glaze the quantity of B_2O_3 that can be

used is below .6 equivalents. The results of this series are consistent with those of series B, in which the best glaze contained .4 B_2O_3. The softening effect of the fritting in series D is obtained in series B by the use of .25 PbO. The color is better in the glaze without lead, and yet the comparison indicates that as much B_2O_3 is permissible in one case as in the other.

Series E. In view of the results obtained in Series C and D it is apparent, that no member of Series E can be satisfactory; for as we go down the list in the table, we see that before we get below the upper limit of PbO, we pass above the upper limit of B_2O_3, and therefore the limit of either PbO or B_2O_3 is exceeded in every number of the series. E–4, whose composition is above the limit in both PbO and B_2O_3, but not far above either, would naturally be selected as the nearest approach of any to a favorable combination.

An inspection of this series shows that the actual results are exactly what we would expect, and are therefore entirely consistent with the preceding series. E–1, E–2 and E–3 resemble C–5 and C–4 which are also high in lead, while E–5 and E–6 are almost identical with D–5 and D–6, containing respectively the same equivalents of B_2O_3. E–4 is not so good as D–4, owing to its lead content. This makes the series consistent throughout.

We may therefore conclude that in glazes of the types employed in these tests:

1. A high lead content destroys the color of the chromium-tin pink.

2. A high content of boracic acid is also detrimental to the pink color, and boracic acid in any quantity gives the color a purple tint.

3. The allowable limit of PbO is below .4 equivalents.

4. The limit of B_2O_3 is below 6. equivalents.

In view of these results, it is apparent that with a glaze of the type employed up to this point, a lead glaze without boracic acid will not answer the purpose: for not only does

a high lead content destroy the pink color, but it also produces a glaze which beads up and will not lie smooth, and the higher the lead content is made, the worse the glaze behaves. Moreover, with a leadless glaze, while it is possible to produce the desired effect at cone 3 or 4 by the use of boracic acid, we find that when sufficient boracic acid is used to mature the glaze at cone 01, the color effect is destroyed. Neither lead nor boracic acid alone is able to soften the glaze—

$$RO,\ 0.2\ Al_2O_3,\ 2.00\ SiO_2 \left\{ \begin{matrix} 0.005\ Cr_2O_3 \\ 0.144\ SnO_2 \end{matrix} \right\}$$

enough to make it mature at cone 01 without being detrimental to the color. Nevertheless, since the effects produced by the lead and boracic acids were opposite in character, it was thought that as much or more of each could be used with the other as without it, combining their softening effects, and neutralizing the detrimental tendencies of each other.

It was therefore decided to make another series, in which both the lead and boracic acid should be regularly increased, in order to determine to what extent each could be used in connection with the other. But before making these tests, it was considered desirable to determine whether it would be feasible to reduce the refractoriness of the glaze by decreasing the ratio of CaO to KNaO, or by decreasing the acidity of the glaze. It was also decided to reduce the quantity of pink fritt in the glaze, as this is one of the refractory agents.

The effect of decreasing the lime-soda ratio was tried by the use of the following series:

SERIES F.

No. of Glaze.	KNaO	CaO	Al_2O_3	SiO_2	Cr_2O_3	SnO_2	Ratio (CaO:KNaO)
1	.333	.666	0.2	2.00	0.003	0.087	2.00:1
2.	.400	.600	"	"	"	"	1.50:1
3	.500	.500	"	"	"	"	1.00:1
4.	.600	.400	"	"	"	"	0.66:1
5.	.666	.333	"	"	"	"	0.51:1

In making F-1, the following fritt was used:

$$\left.\begin{matrix}0.33\ KNaO \\ 0.67\ CaO\end{matrix}\right\} 0.13\ Al_2O_3,\ 1.00\ SiO_2$$

The raw materials added to this fritt to make the glaze were:

Spar	.04 Equivalents
Clay	.047 "
Flint	.698 "

The glaze batch contained over 50 per cent of the lime-soda fritt.

For F-5, a fritt was designed as follows, leaving only .07 equivalents of raw clay to add to the glaze batch:

$$\left.\begin{matrix}0.726\ KNaO \\ 0.24\ CaO\end{matrix}\right\} 0.143\ Al_2O_3,\ 1.94\ SiO_2$$

As a consequence, some allowances should be made in considering these results, for the fact that toward the latter end of this series, a greater proportion of the glaze mixture is fritted and that this tends to reduce the refractoriness somewhat. This difference was probably not great enough to be of much consequence, however.

These glazes were fired in the up-draft test kiln, cone 5 being reached in about fourteen hours. The resulting glazes showed the following effects:

As the ratio of CaO to KNaO decreased, the fusibility increased somewhat, but F-5 was the only one which was fully mature. However, with the increase of fusibility there was an increasing tendency for the glazes to bubble even though immature. The last ones of the series were rough at the edges, while smooth over the surface of the tile. As to color, the detrimental effects of the lower lime-soda ratio was not so great as had been anticipated, yet the color degenerated steadily from a bright pink in F-1 toward brown in F-5.

After making this test, it was decided to continue the use of the hightest ratio — CaO: KNaO=2:1, because the softening effect of the lower ratio was not considered great enough to compensate for the detrimental effect on the color.

Having fixed on a lime-soda ratio, another series was made to determine whether a reduction in acidity would

produce a less refractory glaze. In order that all the conditions except the acid ratio should remain constant in this series, all the ingredients of both extremes were fritted. The series was as follows:

SERIES G.

No. of Glaze	KNaO	CaO	Al_2O_3	SiO_2	Cr_2O_3	SnO_2	Acid Ratio
1.	0.333	0.666	0.200	2.00	.003	.087	2.50
2.	"	"	0.170	1.70	"	"	2.25
3.	"	"	0.143	1.43	"	"	2.00
4.	"	"	0.118	1.18	"	"	1.75
5.	"	"	0.097	0.97	"	"	1.50

This series, like series F, was fired to cone 5 in about fourteen hours. The result was not at all in favor of a lower ratio than 2.5. This glaze, G-1, which is the same as C-1, D-1, and F-1 was slightly immature, as was expected, but of fairly good color. However, as the ratio decreased, no good glazes were produced, all being immature, rough and badly blistered. The color, also, became poorer. It was decided, therefore, that for lime-soda glaze at least the acidity was none too high, and the type glaze RO, .2 Al_2O_3 2 SiO_2 was retained for the remaining series.

As has been stated, the following set of series was designed to demonstrate the combined effects of lead and boracic acid when used together. In each series the lead content was kept constant, while the B_2O_3 was regularly increased by increments of .1 equivalent from nothing up to .5 equivalent, beyond which it was judged unnecessary to go.

The lead content of the first series was placed at .15 equivalent, and each successive series contained an addition of .10 equivalent, making the lead content of the fourth series .45 equivalent, which was supposed to be above the limit.

The series were as follows:

SERIES H.

No.	PbO	CaO	KNaO	Al_2O_3	SiO_2	B_2O_3	Cr_2O_3	SnO_2
1	0.15	0.566	0.283	0.2	2.0	0.0	0.003	0.087
2	"	"	"	"	1.9	0.1	"	"
3	"	"	"	"	1.8	0.2	"	"
4	"	"	"	"	1.7	0.3	"	"
5	"	"	"	"	1.6	0.4	"	"
6	"	"	"	"	1.5	0.5	"	"

SERIES I.

No.	PbO	CaO	KNaO	Al_2O_3	SiO_2	B_2O_3	Cr_2O_3	SnO_2
1	0 25	0.50	0.25	0.2	2.0	0.0	0.003	0.087
2	"	"	"	"	1.9	0.1	"	"
3	"	"	"	"	1.8	0.2	"	"
4	"	"	"	"	1.7	0.3	"	"
5	"	"	"	"	1.6	0.4	"	"
6	"	"	"	"	1.5	0.5	"	"

SERIES J.

No.	PbO	CaO	KNaO	Al_2O_3	SiO_2	B_2O_3	Cr_2O_3	SnO_2
1	0.35	0.433	0.216	0.2	2.0	0.0	0.003	0.087
2	"	"	"	"	1.9	0.1	"	"
3	"	"	"	"	1.8	0.2	"	"
4	"	"	"	"	1.7	0.3	"	"
5	"	"	"	"	1.6	0.4	"	"
6	"	"	"	"	1.5	0.5	"	"

SERIES K.

No.	PbO	CaO	KNaO	Al_2O_3	SiO_2	B_2O_3	Cr_2O_3	SnO_2
1	0.45	0.366	0.183	0.2	2.0	0.0	0.003	0.087
2	"	"	"	"	1.9	0.1	"	"
3	"	"	"	"	1.8	0.2	"	"
4	"	"	"	"	1.7	0.3	"	"
5	"	"	"	"	1.6	0.4	"	"

The glazes of these series were made by blending the three following glazes:

1. A raw lead glaze nearly as high in lead as the lime and alkalies, introduced by the pink fritt would permit:

$$\left.\begin{matrix}0.800\ PbO\\0.133\ CaO\\0.066\ KNaO\end{matrix}\right\}\ 0.2\ Al_2O_3,\ 2.0\ SiO_2\left\{\begin{matrix}0.003\ Cr_2O_3\\0.087\ SnO_2\end{matrix}\right.$$

2. A fritted boracic acid glaze:

$$\left.\begin{matrix}0.666\ CaO\\0.333\ KNaO\end{matrix}\right\}0.2\ Al_2O_3\left\{\begin{matrix}1.0\ SiO_2\\1.0\ B_2O_3\end{matrix}\right.\left\{\begin{matrix}0.003\ Cr_2O_3\\0.087\ SnO_2\end{matrix}\right.$$

This glaze was made without any raw ingredients, using the pink fritt and one of the following composition:

$$\left.\begin{matrix}0.641\ CaO\\0.359\ KNaO\end{matrix}\right\}0.2\ Al_2O_3\left\{\begin{matrix}0.991\ SiO_2\\1.100\ B_2O_3\end{matrix}\right.$$

In all the Series except A and B, the pink fritt given for Series C has been used.

3. A fritted lime-soda glaze, made exactly as described for F-1, as follows:

$$\left.\begin{matrix}0.666\ CaO\\0.333\ KNaO\end{matrix}\right\}0.2\ Al_2O_3,\ 2.00\ SiO_2\left\{\begin{matrix}0.003\ Cr_2O_3\\0.087\ SnO_2\end{matrix}\right.$$

With these three glazes it was possible to make blends covering all combinations within the limits assigned. The calculations were made as follows: Suppose I-4 were to be made. This glaze contains .25 equivalent PbO and 0.3 B_2O_3. The lead extreme contains .8 equivalents PbO; therefore, we must use $0.25 \div 0.80 = .312$ equivalents of the lead glaze. For the B_2O_3 we take $0.3 \div 1 = .3$ equivalent of the boracic acid glaze. This make $0.312 + 0.3 = .612$ equivalent, leaving $1.000 - 0.612 = .388$ equivalent of the lime-soda glaze. Knowing the equivalent weight of each glaze, we have but to multiply each decimal by the corresponding equivalent weight for the batch weight.

These glazes were placed on end in saggers, which were then luted tight and placed in the down draft test kiln. The kiln was burned in about fourteen hours, cone 1 being reached. The results can be stated best by describing the individual pieces:

Series H. PbO=0.15.

H–1. Immature, rather pale pink with a margin of white enamel.

H–2. Glaze slightly darker and more nearly mature than H–1.

H–3. Glaze fused enough to develop a strong dark color, but not enough to run smooth. Scummed.

H–4. Glaze mature and color well developed but shows a tendency to segregate. Has run too much, leaving the color too thin near the top.

H–5 and 6. As the B_2O_3 is raised the tendency to flow increases, leaving the color too thin on the tile. The glazes tend toward greenish, but segregations of pink remain.

Series I. PbO=0.25.

I–1. Glaze beaded and immature, color inferior. White margin.

I–2. Still beaded but somewhat smoother and better color.

I–3. Glaze fairly smooth and of good color. Has run a little, leaving color rather thin and uneven near top. Scummed slightly.

I–4. Glaze mature and brilliant. Has run freely and the color is not dense enough near the top in consequence.

I–5 and 6. Pale glazes mottled with pink segregations. Pronounced green tint in No. 6.

Series J. PbO=0.35.

J–1. Badly beaded, poor color, white margin. Same tendencies as in I–1, but carried to a greater extent.

J–2. Beaded, most of the tile bare, but color fairly well developed.

J–3. Glaze nearly mature, color fair except at margin. Glaze has not run.

J–4. Mature. Has run considerably, small portions of the tile bare, color fair but not well distributed—similar to H–5 and I–5.

J–5. About like I–6.

J–6. Greenish glaze, mottled with pink.

Series K. PbO=0.45.

K–1. Beaded worst of all but the color not destoyed.

K–2. Still bad.

K–3. Not yet smooth, some spots bare, others thick. Pale margin at top.

K–4. Glaze mature and fairly smooth. Has run considerably. Color uneven and inferior.

K–5. Pale green glaze with only a faint trace of pink.

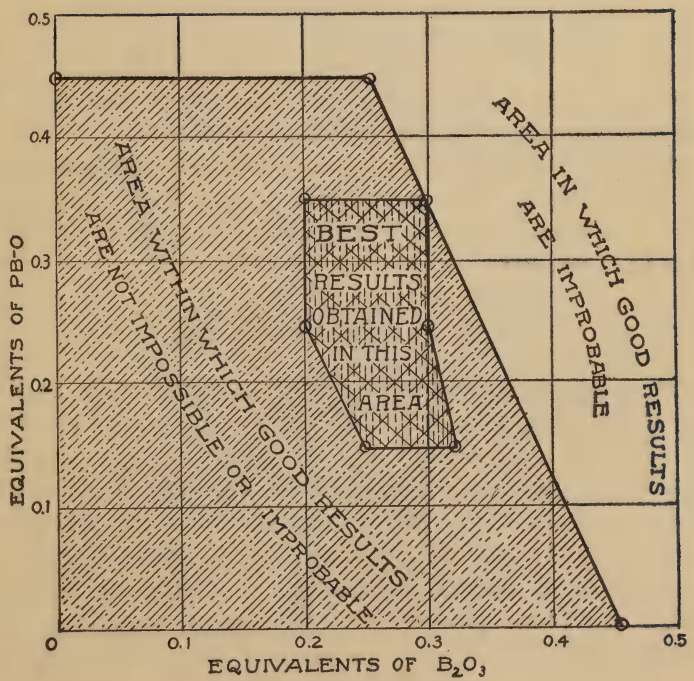
A review of these results brings out the following points:

1. In producing a chromium-tin pink glaze at low temperature, it is best to use both lead and boracic acid.

2. The more lead the glaze contains, the more boracic acid is required to overcome the tendency to bead; but the greater the lead content in the glaze, the less boracic acid can be used without destroying the color. This places a limit on the allowable lead content. These results indicate that this limit is below .45 equivalent of PbO.

3. Although more boracic acid can be used in glazes low in lead than in those with a high lead content, yet, even in leadless glazes, too much boracic acids destroys the pink color. As stated before, this limit is below 0.6 equivalent B_2O_3—probably below 0.5 B_2O_3.

The following diagram roughly defines the limits of PbO and B_2O_3 when used together for this purpose in a glaze of this type; all those combinations within the curve may be considered permissible so far as color is concerned, and may be expected to mature at some temperature. The most favorable combinations for cone .01 to cone 1 are within the cross-hatched area.



THE BEHAVIOR OF THE DIFFERENT PINK FRITTS IN THE SAME GLAZE.

These series of pink fritts have already been described. To these was added a fourth series, showing the effect of lime in the fritt.

SERIES A-IV.

No.	CaO	SnO_2	SiO_2	Cr_2O_3
19	0.00	1.00	2.00	0.0375
20	0.25	"	"	"
21	0.50	"	"	"
22	0.75	"	"	"
23	1.00	"	"	"
24	1.50	"	"	"
25	2.00	"	"	"
26	3.00	"	"	"

These fritts were prepared in a manner similar to that described for the previous fritt series. The appearance of the fritts was as follows:

19. Pale and inferior color with a greenish tint.

20. Somewhat stronger pink.

21. The color improves up to 22 with 0.75 CaO. From 22 upward, the color runs steadily toward brown, and the powder shows an increasing tendency to vitrify.

A glaze was now selected in which the different fritts were to be incorporated, in order to demonstrate the coloring effect of each in the glaze. The glaze used for the purpose was the following:

$$\left.\begin{matrix}0.25\ PbO\\0.50\ CaO\\0.25\ KNaO\end{matrix}\right\}\ 0.2\ Al_2O_3\ \left\{\begin{matrix}1.75\ SiO_2\\0.25\ B_2O_3\end{matrix}\right.$$

This glaze was prepared, and a portion of slip equivalent to forty five grams of dry glaze was weighed out for each fritt. Five grams of each fritt to be tested were then weighed out and each portion ground wet in an agate mortar and screened through a 200 mesh sieve into the receptacle containing the corresponding portion of glaze slip. The glaze was then stirred thoroughly to distribute the fritt through it. These glazes were then dipped, set and burned to cone 1, as described for the last set of series preceding.

The results may be described as follows:

The fritts of Series A-I, made from chromic acid and stannic oxide alone did not color the glaze well. No. 2 produced purple specks in the glaze, but poorly disseminated. In No. 4 the color was nearly destroyed, indicating that the proportion of chromic oxide was too high.

Of fritt Series A-II, containing 1 SnO_2, 0.0375 Cr_2O_3 and CaO varying, No. 10 with .391 CaO and No. 11 with 1.04 CaO were tried. Both gave good strong colors. The glaze of No. 10 was slightly scummed, while that of No. 11 was scummed badly and was less mature.

In Series A-III No. 15 produced a color not dissimilar to that produced by the Seger fritt, but somewhat lighter and perhaps a little better distributed. In 16 and 17 the color becomes weaker, owing to dilution of the fritt by silica.

The fritts of Series A-IV all produced fairly good colors. The glazes containing the fritts highest in lime, scummed worst, probably due to the fact that the higher lime content made the glazes more refractory.

The Seger fritt and my modification of the Seger fritt were also tried, and the effects were very similar to most of the others described.

These results indicate that a wide range in variation in the quantity of lime and silica used in the fritt is allowable, and that the color of the fritt is not a sure indication of the color which it will produce in a glaze. In this set of tests the best colors were produced by the fritts which contained no silica, but this was probably due to the fact that five grams of the flintless fritt represented a larger quantity of the other ingredients, and therefore had a greater coloring power. It seems that almost any combination of tin with a very small proportion of chromium, together with some lime or silica will make a fritt which is capable of producing a good pink color in glazes of the type—RO, 0.2 Al_2O_3, 2 SiO_2, provided that the ratio of lime to the alkalies in the glaze be kept high and the content of lead and boracic acid be kept within the limits assigned. It is not known to what chemical action the production of the pink color is due, but it is evident that while a high temperature is necessary for the

development of a fritt which will produce the pink color in a glaze, yet the action of the glaze at a comparatively low temperature, has the effect of changing the color of the fritt. The content of lime and the content of silica both have a marked effect on the color of the fritt, and yet a fritt containing silica and no lime, produces in the glaze a color similar to that developed by a fritt containing lime and no silica.

On the other hand, as has been demonstrated, a glaze too low in either lime or silica, is detrimental to the color. These observations lead one to emphasize the statement of Mr. Mayer, that in producing the different variations of this color, the greater part of one's attention should be paid to the composition of the glaze, and not to that of the pink fritt.

THE FLUXING POWER OF MICA IN CERAMIC BODIES.

BY

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All clays contain mica, which is generally present in small amounts, but in some cases it comprises a considerable portion of the mass, sometimes reaching as high as 30 per cent.

The real effect of mica upon the refractory properties of a clay is not definitely known. At the present time but very little can be found in ceramic literature pertaining to the effect of mica in ceramic mixtures. Langenbeck, in his book entitled "The Chemistry of Pottery," speaks of mica as a flux, but gives no evidence as proof of this statement. "Technology of Ceramics," by Auscher et Quillard, says that mica should impart resistance and fusibility to a clay. What is here meant by resistance is rather vague, but probably refers to the strength of the body. The authors appear to be somewhat uncertain in regard to this statement, by using the word "should."

Ceramists hold that the fluxing value of feldspar is due to its alkali content. If the alkali is the real fluxing agent, then it seems reasonable to suppose that any other alkali bearing mineral would be equally good as a flux, in proportion to its alkali content. Others are of the opinion that a molecule of the fluxing mineral acts as a unit until the temperature is reached, at which fusion or decomposition of the mineral begins to occur. This fusion or decomposition may be brought about at a lower temperature by the action of some other substance upon it. This is generally the case of a flux acting upon a flux. In this way a high fire flux may be made to exert its fluxing power at a temperature far below that at which it would otherwise occur.

The white micas are divided into two groups, the alkali micas and the magnesian micas. The alkali micas form a group of minerals whose formulæ run somewhat parallel to those of the feldspars; the principal difference is that these

micas are generally higher in alumina. The close similarity in chemical construction of muscovite mica with that of orthoclase feldspar is, perhaps, one reason for their close association in nature. This close association accounts for the fact that the mica found in white clays is almost invariably the muscovite mica.

The formulæ given for orthoclase feldspar and muscovite mica are:

Orthoclase feldspar, K_2O, Al_2O_3, 6 SiO_2
Muscovite mica, K_2O, 3 Al_2O_3, 6 SiO_2, 2 H_2O

The similarities in composition are:

1. Each contains K_2O, Al_2O_3 and SiO_2.
2. Each contains one molecule of K_2O.
3. Each contains six molecules of SiO_2.

The dissimilarities in composition are:

1. Muscovite has 3 Al_2O_3 against 1 Al_2O_3 in orthoclase.
2. Muscovite has 2 H_2O against none in orthoclase.

The ratio of K_2O to SiO_2 in each is 1 to 6. In so far as the K_2O is concerned, each mineral would have the same fluxing advantage. In orthoclase, the ratio of Al_2O_3 to SiO_2 is 1 to 6, while in muscovite the ratio is 3 to 6.

Seger found that by starting with pure alumina and making increased additions of silica, he could reduce the refractory qualities of the mixture up to a molecular ratio of Al_2O_3 to $SiO_2 = 1:17$, which gave him the most fusible combination of alumina and silica. On further additions of silica, the refractoriness of the mixture began to increase.

From this, the natural conclusion would be that the ratio, Al_2O_3 to $SiO_2 = 3$ to 6 in muscovite is more refractory than 1 to 6 in orthoclase. But, however, we cannot depend upon the theoretical assumption that the ratios of RO to SiO_2 and Al_2O_3 to SiO_2 determine the refractoriness, fluxing power or fusibility of a mineral when incorporated as a ceramic mixture, since the presence of other ingredients may materially change these qualities.

It was the object of the following work to determine, if possible, whether muscovite mica acted as a flux or whether it imparted refractory properties to a ceramic body, when fired at temperatures within the range for burning white

biscuit ware. Also, if it did have a fluxing power, how would it compare to that of orthoclase feldspar under the same conditions?

THE MATERIALS AND THEIR PREPARATION.

The materials used in this experiment were: 1 muscovite mica; 2 Brandywine feldspar; 3 Florida ball clay; 4 Golding flint.

The mica was the scrap variety from Jackson County, N. C. When received it ran in sizes from three inches across by one-half inch thick down to very small, thin flakes. In the laminae of some of the pieces were stains of iron. When observed, such pieces were rejected.

The mica was placed in a ball mill twenty-four inches in diameter by twenty-five inches in length. Three hundred and fifty pounds of Iceland flint pebbles were used, and sufficient water added to cover the balls three inches deep. The mica was allowed to grind for fifteen hours at thirty-six revolutions per minute. Owing to the tough nature of the mica, this long period of grinding was resorted to in order to reduce it as nearly as possible to the same degree of fineness as that of the feldspar, so that the two minerals should have the same advantages in fineness of grain. After grinding, the mica was removed from the mill, and screened through a laun of 120 meshes to the linear inch. That portion which remained on the laun was rejected, and represented less than 10 per cent. of the original batch. The portion which passed through the laun was placed in a tall can, allowed to settle over night, the supernatant liquid siphoned off, and the mica pulp evaporated to dryness.

The mica pulp when dry was nearly white in color, having a delicate light gray appearance. It was reduced to such a degree of fineness that the unaided eye could scarcely distinguish the fine mica flakes. On moistening with water it took on a dark gray appearance and developed a surprising degree of plasticity; in fact, it showed a greater degree of plasticity than some clays which are being worked successfully at the present time. This tends to prove that plasticity in kaolinite is due to fineness of grain and thin plate-like structure.

The commercially ground feldspar was taken from the bin, blunged thoroughly with water and screened through a 120 mesh laun in order to insure the proper degree of fineness, and to free it from woody fibre and other foreign material. But very little feldspathic residue was left on the laun. The portion passing through the laun was placed in a tall can, allowed to settle, decanted and dried in the same way as was done in the preparation of the mica.

The commercially prepared Florida ball clay, better known as Florida kaolin, was blunged to a thin slip and passed through the 200 mesh laun for the purpose of eliminating the foreign matter, and to take out as much of the mica as was possible to do. In this way over 0.5 per cent. of the weight of clay was removed as mica. The clay was allowed to settle, decanted and dried.

As the flint was known to be a very pure variety and of the proper degree of fineness, it was used from the bin without any extra preparation.

ANALYSES OF THE MATERIALS.

	Mica	Feldspar	Kaolin	Flint
SiO_2	66.14	66.39	45.69	99.23
Al_2O_3	17.57	19.13	39.28	....
Fe_2O_3	5.12	.19	.40	.51
CaO	1.20	.42	.90	....
MgO	.76	.12	.18	....
K_2O	5.31	12.01	.13	....
Na_2O	.99	1.83	.00	....
H_2O	3.02	.00	13.61	....
Total	100.11	100.09	100.19	99.74

The molecular formulæ calculated from these analyses, taking Al_2O_3 as unity, are:

MUSCOVITE, FORMULA NO. 1.

$$\left.\begin{matrix}.1243\ CaO\\ .1103\ MgO\\ .3280\ K_2O\\ .0929\ Na_2O\end{matrix}\right\}\ 1.0000\ Al_2O_3\ \left\{\begin{matrix}.1857\ Fe_2O_3\end{matrix}\right\}\ \left\{\begin{matrix}6.399\ SiO_2\ (.974\ H_2O)\end{matrix}\right.$$

.6555 RO

Combining weight, 582.167

FELDSPAR, FORMULA NO. 2.

$$\left.\begin{matrix}.0400\ CaO \\ .0160\ MgO \\ .6812\ K_2O \\ .1574\ Na_2O\end{matrix}\right\} 1.0000\ Al_2O_3 \left\{ \begin{matrix} \\ .0063\ Fe_2O_3 \end{matrix}\right. \left\{ 5.900\ SiO_2 \right.$$

.8946 RO — Combining weight, 533.679

FLORIDA KAOLIN, FORMULA NO. 3.

$$\left.\begin{matrix}.0417\ CaO \\ .0117\ MgO \\ .0036\ K_2O\end{matrix}\right\} 1.0000\ Al_2O_3 \left\{ \begin{matrix} \\ .0065\ Fe_2O_3 \end{matrix}\right. \left\{ 1.977\ SiO_2\ (1.963\ H_2O) \right.$$

.0560 RO — Combining weight, 260.167

In the mica formula it will be observed that the molecular ratio of K_2O to Al_2O_3 is approximately 1 to 3, which corresponds to the theoretical formula for muscovite. Attention is also called to the high percent of silica in the mica. This may be accounted for by the wear upon the flint pebbles during the long period of grinding. The "Chemistry of Geology," Volume II, by Bischoff, gives as the limits of composition for mica:

SiO_2	36 to 71
Al_2O_3	6 " 38
Fe_2O_3	0 " 36
MgO	0 " 29
K_2O	2 " 14

Undoubtedly some silica was introduced by the wear upon the flint pebbles, but nevertheless it is more than likely that the mica was the highly silicious variety.

MAKING THE BODIES.

Two body series were made, Series A and Series B. Series A consisted of eleven bodies, first starting with 100 percent Florida kaolin, decreasing the kaolin each time by 10 per cent. and adding a corresponding amount of ground mica, up to all mica and no kaolin. These bodies were marked A-1, A-2, A-3, etc., up to A-11. The composition of Series A by weight is:

A-1	100	Kaolin	0	Mica
A-2	90	"	10	"
A-3	80	"	20	"
A-4	70	"	30	"
A-5	60	"	40	"
A-6	50	"	50	"
A-7	40	"	60	"
A-8	30	"	70	"
A-9	20	"	80	"
A-10	10	"	90	"
A-11	0	"	100	"

These bodies were made for the purpose of determining whether mica had any fluxing action upon kaolin, or if it had any vitrifying properties alone.

If mica exerted a fluxing power, it was also desirable to know how this fluxing power compared with that of feldspar in an ordinary whiteware body, and to what extent it could take the place of feldspar in such a body, and its effect upon the general appearance of the body.

For this purpose Series B was made. This was done by blending two bodies, each one having the same chemical formula. The only difference in these two bodies was that the first one called "S" was made from flint, kaolin and feldspar, while the second, which was marked "M," was made from kaolin, flint and mica, without the use of feldspar.

As a starting point for making this series, a well known whiteware body was selected which would give a comparatively wide range of vitrification, shrinkage and porosity, within the temperature range for burning ordinary white biscuit ware. The batch weights for this body are:

Florida Kaolin.....	50%
Golding Flint.....	38
Brandywine Spar.....	12

Considering the flint as pure SiO_2, and using the formulæ for the kaolin and feldspar according to their ultimate analyses, the formula for this body figures:

FORMULA NO. 4.

$$\left.\begin{array}{l} .0415\ CaO \\ .0121\ MgO \\ .0758\ K_2O \\ .0165\ Na_2O \end{array}\right\} \begin{array}{l} 1.0000\ Al_2O_3 \\ .0065\ Fe_2O_3 \end{array} \left\{ 5.338\ SiO_2 \right.$$
$$\overline{.1459\ RO}$$

Body "M" was made by taking the proper proportions of Florida kaolin and mica so as to furnish all the RO and Al_2O_3 in formula No. 4, and supplying the difference in SiO_2 by flint.

The calculation of Body M was as follows:

Let X = equivalent of kaolin
Let Y = " " mica

required to supply .1459 RO and 1.000 Al_2O_3. Then

.0574 X RO in kaolin + .6555 Y RO in mica = .1459 RO in formula 4
Also, X Al_2O_3 in kaolin + Y Al_2O_3 in mica = 1.000 Al_2O_3 in formula 4
X = .8514 equivalents of kaolin
and Y = .1486 " " mica

.8514 equivalents kaolin + .1486 equivalents mica give

$$.1459\ RO \left\{ \begin{matrix} 1.000\ Al_2O_3 \\ .033\ Fe_2O_3 \end{matrix} \right\} 2.623\ SiO_2$$

Then there remains 5.338—2.623 = 2.715 equivalents of flint to be added. The batch weights for body "M" are:

Kaolin	47.04%
Flint	34.59
Mica	18.37

Calculating the formula of this mixture as a check upon our operations, we find the following formula for body "M.',

FORMULA NO. 5.

$$\left.\begin{matrix} .0540\ CaO \\ .0263\ MgO \\ .0518\ K_2O \\ .0138\ Na_2O \end{matrix}\right\} \left\{ \begin{matrix} 1.000\ Al_2O_3 \\ .033\ Fe_2O_3 \end{matrix} \right\} 5.338\ SiO_2$$
$$.1459\ RO$$

In supplying the total RO and Al_2O_3 in formula No. 4 by kaolin and mica alone, the Fe_2O_3 has been overburdened by an amount .033—.0065 = .0265. This equivalent of Fe_2O_3 was added to formula No. 4, giving formula No. 6 as the formula for body "S."

FORMULA NO. 6.

$$\left.\begin{matrix} .0415\ CaO \\ .0121\ MgO \\ .0758\ K_2O \\ .0165\ Na_2O \end{matrix}\right\} \left\{ \begin{matrix} 1.000\ Al_2O_3 \\ .033\ Fe_2O_3 \end{matrix} \right\} 5.338\ SiO_2$$
$$.1459\ RO$$

In comparing formula No. 6 with that of No. 5, it is observed that the two have the same chemical equivalent of RO, and that they have the same Al_2O_3, Fe_2O_3 and SiO_2. In comparing the RO in No. 6 with that of No. 5, we see that No. 5 is higher in CaO and MgO, and correspondingly lower in K_2O and Na_2O, thus giving body "S" containing spar a slight advantage in fusibility over body "M" containing mica.

The batch weights for body "S" calculated from formula No. 6 are:

Kaolin	49.93%
Flint	37.81
Spar	12.16
Fe_2O_3	.10

Bodies "M" and "S" were each weighed from the dry materials, placed in separate porcelain lined ball mills and ground wet for thirty minutes. The two batches were then removed, screened through a 100 mesh screen, and placed in two separate cans. The percent of solid material per unit weight of slip was determined for each, and Series "B" was made by blending these two slips, as follows:

B-1	100	Body "S"	0	Body "M"
B-2	90	"	10	"
B-3	80	"	20	"
B-4	70	"	30	"
B-5	60	"	40	"
B-6	50	"	50	"
B-7	40	"	60	"
B-8	30	"	70	"
B-9	20	"	80	"
B-10	10	"	90	"
B-11	0	"	100	"

Each body of the series was thoroughly mixed by blunging, and dried on concave plaster slabs down to stiff mud consistency, for the purpose of making into brickettes.

MAKING THE TRIAL PIECES.

For each of the bodies in Series A and Series B, brickettes were made 3½ x 1 x ½ inches. Two pin points were made on each brickette three inches apart for the purpose of measuring shrinkage, and the brickettes dried carefully so as to prevent warping.

BURNING THE TRIALS.

Brickettes from each body of the two series were burned at two different temperatures, cone 4 and cone 9. For the cone 4 burn cones 2, 3, 4 and 5 were placed on a slab at the center of a large sagger, and the brickettes placed around the cones in close proximity to them. The sagger was luted tight, placed at the center of the small updraft kiln, and fired

with coke as fuel for a period of eight hours, when cone 5, which was placed outside of the sagger, went down. It was observed in previous burns that there was a difference in the temperature between the outside and inside of the sagger, of approximately one cone.

On taking the trials from the kiln, it was found that cone 4 was down so that its point touched the slab, and cone 5 had began to curl.

The cone 9 burn was originally intended for cone 8. The trials were set in the same way as in the cone 4 burn, cones 6, 7, 8 and 9 being placed in the center. Coke was the fuel used, and the firing period lasted ten hours. Cone 9 was fired flat outside of the sagger. On taking the trials from the kiln, it was found that cone 8 inside the sagger was nearly flat, and cone 9 was down so that the point touched.

APPEARANCE OF TRIALS.

Series A in the cone 4 burn showed a gradual darkening in color from the kaolin-white in body A-1, down to a dark brownish gray in body A-11. The cone 9 burn gave a gradation in color from the white in A-1 to a stoneware gray in A-11. The colors at cone 9 were much lighter than at cone 4; in fact the brown had entirely disappeared.

Brickettes containing 50 per cent. or more of mica were highly vitrified in the cone 9 burn, and had the appearance of being thinly glazed. Such trial pieces had approached the first stages of fusion, as they were filled with minute bubbles and had swelled considerably.

No difference in general appearance could be detected between the two extremes of Series B, the entire series being a light ivory yellow in color for the cone 4 burn. In the cone 9 burn the yellow had disappeared, giving a biscuit which was nearly white.

DETERMINING FIRE SHRINKAGE AND POROSITY.

Before placing the trials in the kiln each brickette was carefully measured, and after firing, measurements were again taken. The loss in length due to fire shrinkage, divided by the dry length before firing, gave the percent of fire shrinkage.

Porosity was determined by absorption. Each brickette was weighed in the dry, burned condition on the balances, soaked in distilled water for forty-eight hours, removed, the superficial moisture wiped off and again weighed. The difference between wet and dry weights gave the grams of water absorbed by the pores. The weight of water absorbed, divided by the weight of the brickette before absorption, gave a ratio for the comparison of porosity. The following table gives the fire shrinkage and porosity for each body of the two series:

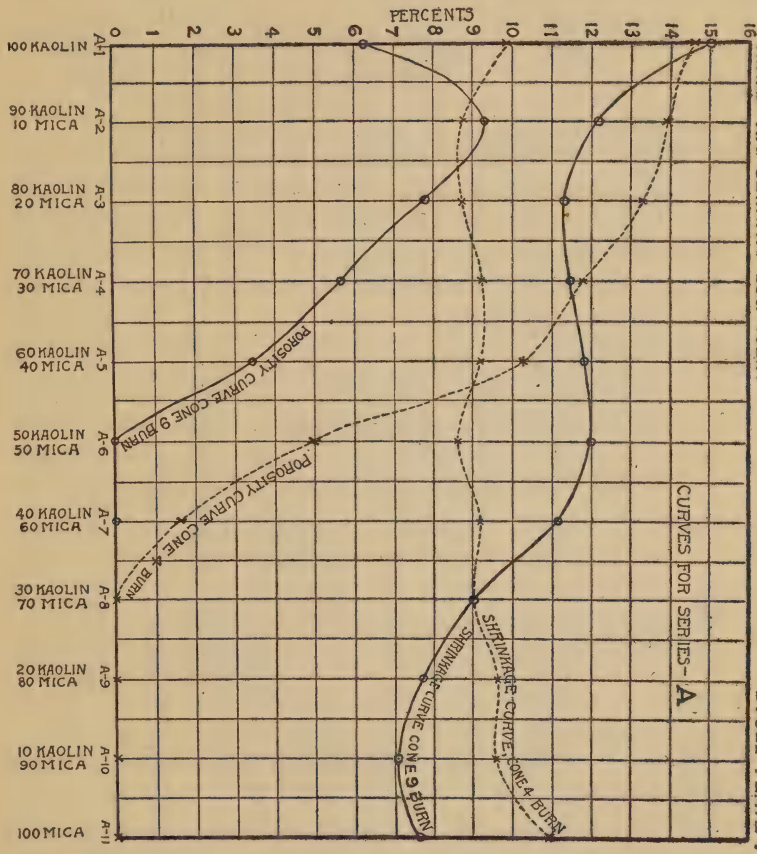
	Fire Shrinkage		Porosity	
	Cone 4	Cone 9	Cone 4	Cone 9
A- 1	9.87	15.13	14.58	6.34
A- 2	8.78	12.16	13.96	9.25
A- 3	8.78	11.41	13.40	7.88
A- 4	9.24	11.48	11.80	5.67
A- 5	9.21	11.84	10.24	3.43
A- 6	8.67	12.00	5.03	.00
A- 7	9.15	11.11	1.62	.00
A- 8	9.03	9.03	.05	.00
A- 9	9.68	7.80	.00	.00
A-10	9.61	7.01	.00	.00
A-11	10.90	7.60	.00	.00
B- 1	5.52	8.79	13.39	6.64
B- 2	4.97	7.69	14.13	6.81
B- 3	5.06	7.86	14.49	6.70
B- 4	4.47	7.18	15.23	7.74
B- 5	4.44	7.73	14.96	7.58
B- 6	3.87	7.14	16.13	7.97
B- 7	3.89	7.18	16.36	7.85
B- 8	3.91	7.22	16.70	8.22
B- 9	3.89	6.63	17.37	10.16
B-10	3.33	6.04	18.12	11.20
B-11	3.31	5.52	18.26	11.71

These results when plotted on curve sheets give some very interesting curves for study. On the following curve sheets the solid lines represent curves for the cone 9 burn, and the broken lines curves for the cone 4 burn.

STUDY OF THE CURVES.

In general, the shrinkage curve for the cone 4 burn shows a decrease in shrinkage from a content of 0 per cent. mica to 10 per cent. mica. From 10 per cent. to 70 per

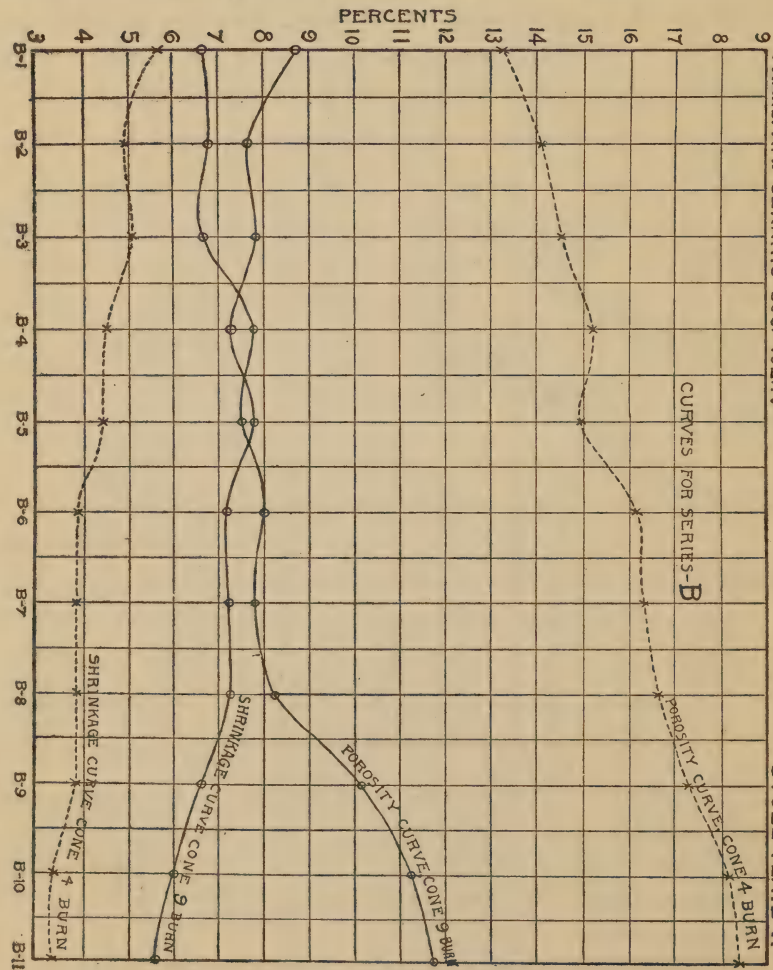
cent. mica the shrinkage is practically constant. From 70 per cent. to 100 per cent. mica there is an increase in shrinkage showing pure mica to have a shrinkage of 1 per cent. more than that of pure kaolin.



In the curve for the cone 9 burn there is a decrease in shrinkage from pure kaolin up to 20 per cent. mica. From 20 per cent. mica to 50 per cent. mica, the shrinkage increases. From 50 per cent. mica to pure mica the shrinkage drops.

Comparing the two shrinkage curves we see that they have a tendency to run parallel up to 50 per cent. mica. Beyond this point the tendeny is to run in opposite direc-

tions up to 90 per cent. mica. From 70 per cent. to 100 per cent. mica, the cone 4 burn has a greater shrinkage than the cone 9 burn. The difference in direction of the curve and in the decrease in shrinkage of the trials in the cone 9 burn, are accounted for by the swelling of the trial pieces when they contained from 50 per cent. to 100 per cent. mica. This was due to the vesicular structure produced in the advanced stage of vitrification or first stage of fusion.



The porosity curve for the cone 4 burn shows a continual decrease in porosity throughout, having no porosity

at 80 per cent. mica. In the cone 9 burn the curve shows an increase in porosity from 0 per cent. to 10 per cent. mica. From this point on porosity decreases, and when the content of mica reaches 50 per cent. porosity becomes zero. From a content of 10 per cent. mica, the two porosity curves run parallel.

With but one exception, the two porosity curves show that mica has exerted a fluxing action upon kaolin.

The one exception is a content of 10 per cent. mica in the cone 9 burn, where the porosity is greatest for that burn. This leads to the supposition that a content of 10 per cent. mica acts as a non-flux. This is also evidenced by the cone 4 and cone 9 shrinkage curves, which have their greatest falling off in shrinkage from pure kaolin to a content of 10 per cent. of mica.

The two shrinkage curves for Series B show a falling off in shrinkage from B–1 containing the feldspar to B–11 containing the mica. From B–6 to B–9 in the cone 4 burn, shrinkage remains constant. From B–6 to B–8 in the cone 9 burn, shrinkage also remains constant.

Both porosity curves for Series B show an increase in porosity from B .1 to B–11.

From the curves of Series B it is evident that mica has exerted a fluxing action, and that this fluxing action is less than that of feldspar.

SOURCES OF SHRINKAGE.

Fire shrinkage depends upon two factors, first, molecular contraction or condensation, and second, silicate formation produced by fluxing action. The latter shrinkage then depends upon the degree of vitrification brought about by the flux or fluxes present. When the flux has exerted no action, the body has had no secondary shrinkage—*i. e.*, this shrinkage is zero. When the flux has exerted its greatest power, then the body has its greatest shrinkage.

If the flux is present in sufficient quantities, the greatest shrinkage is at the point of the complete fusion. If the flux is present in small amounts, it may exert its full fluxing power long before fushion is reached, if no other flux is

present to continue the action. When the fluxing action has ceased, then the shrinkage depending upon it has ceased. Therefore, neglecting the shrinkage due to condensation the amount of which we do not know, it seems safe to say that the total shrinkage is roughly proportional to the fluxing power of the fluxes used. If we have two fluxes, which we will call C and D and place them under the same conditions and find that the body in which C was used gives a shrinkage of 5.52 per cent. and the body containing D gives 3.31 per cent. shrinkage, then

$$\frac{\text{Fluxing power C}}{\text{Fluxing power D}} = \frac{5.52}{3.31}$$

or fluxing power C is to fluxing power D=1 to 0.6. This is the case for Series B in the cone 4 burn. B–1 containing feldspar has a shrinkage of 5.52 per cent. and B–11 containing mica has 3.31 per cent. Since the difference in shrinkage due to molecular condensation is so small, we can take the above ratio as correct for all practical purposes.

B–1 contains 12.16 per cent. feldspar, and B–11 18.37 per cent. feldspar and B–11 18.37 per cent. mica by weight. Since the two bodies have the same general chemical constitution, we can say that the proportionate fluxing power of 12.16 pounds feldspar to 18.37 pounds mica=1 to 0.60 when placed under these conditions, and fired at the temperature of cone 4.

In the same way we find the proportionate fluxing power of 12.16 pounds feldspar to 18.37 pounds mica=1 to 0.63 when fired at the temperature of cone 9.

We see that these two proportions are practically the same. Multiplying the second and fourth members of the proportion by ten-sixths, gives the proportionate fluxing powers of 12.16 pounds spar to 30.61 pounds mica=1 to 1. Then 30.61 parts of mica are required in this case to produce the same fluxing action as 12.16 parts of feldspar, or 2.307 equivalents of mica produce the same fluxing power as one equivalent of feldspar, other things being equal.

CONCLUSIONS.

Drawing conclusions from the foregoing work, we have proven :

First. Mica, if fine enough, is plastic; hence, it need not necessarily cut down the plasticity of the clay.

Second. Mica, if fine enough, exerts a fluxing action upon kaolin and upon ceramic mixtures at temperatures below cone 4.

Third. Mica alone, when reduced to an extremely fine powder, vitrifies sufficiently to produce a non-absorbent body below the temperature of cone 4.

These results are contrary to the opinions expressed by the majority of ceramists. That mica is here proven to be a flux confirms the statement of Langenbeck and of Auscher et Quillard. Vogt, the eminent director of the National Porcelain Manufactory at Sevres, France, has shown that mica does not fuse at 1300 degrees C, but the condition under which the result was obtained is not known to the writer.

Mayer* and others have expressed their opinion in regard to the refractory qualities of mica by citing instances of finding mica flakes unchanged in the ware after passing the biscuit fire. These statements in regard to the refractory properties of mica, do not necessarily oppose the foregoing conclusions of this work. A substance to be an efficient and satisfactory body flux must be present in a fine state of division and disseminated uniformly throughout the mass. Substances present in coarse grains do not lose their identity, even when the mass is vitrified so as to be non-absorbent. Too much stress cannot be placed upon the advantages gained in fineness of grain. The finer the materials are prepared and the more intimately they are mixed, the nearer we get molecule to molecule, which materially aids both chemical action and fusion.

The mica used in this work was ground as fine as the feldspar, hence it had that same advantage of fusibility and chemical activity, in so far as fineness of the grain was concerned. Under these fair conditions we find that mica is unmistakably a flux, though not so good as feldspar.

*Vol. II, Trans. A. C. S., pp. 98, 99.

SOME GAPS IN OUR KNOWLEDGE OF CEMENTS.

(A NOTE.)

BY

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Notwithstanding the enormous development in the manufacture of cement, there yet remain many unanswered questions pertaining to its composition, its properties and peculiar reactions, some of which so far have baffled the most ingenious and refined attacks of research. It is the aim of this note to indicate a few of these problems to those who have not made a special study of this line.

Though apparently the composition of cements is a simple matter from the chemical standpoint, since it deals mainly only with the silicates and aluminates of lime and magnesia, we have at present no definite knowledge of the process of formation of these salts. We know in a general way that, with increasing temperatures, the basicity of the silicates and aluminates is increased, but exact information as to the proportions involved in these heat reactions is still lacking. Thus for instance, we are still at a loss to trace the connection between natural and Portland cements. This state of affairs is due to the fact that we are not yet in possession of data involving the examination of all the possible heat reactions with the help of accurate temperature measurements. It is absolutely essential to understand the fundamental principles involved in the formation of the simpler calcium compounds, before conclusions can be reached with reference to the complex combinations of Portland cement. If the elaborate experiments carried on by some of our able investigators were directed along this line, instead of dealing exclusively with such difficult problems as the determination of free lime in Portland cement, more rapid progress could perhaps be made. Synthesis certainly promises more direct results than analysis.

A series of synthetical compounds ranging, say, from 0.5 CaO (MgO) SiO_2 to 3.0 CaO (MgO) SiO_2, and from 0.5

CaO (MgO) Al_2O_3 to 2.0 CaO (MgO) Al_2O_3 burnt at different temperatures, exactly determined, is bound to produce results which will assist materially in clearing up the chemical laws governing the development of hydraulicity. In preparing these mixtures it is, of course, important that the materials be ground together as intimately as possible under exactly uniform conditions. Mere mixing is bound to be unsatisfactory. The progress of the combination with increasing temperatures can be followed by the following means:

1. Determination of the soluble silica (soluble in HCl and Na_2CO_3 solution) in the case of the lower lime compounds.

2. The heat of reaction of the resulting compounds as determined by the calorimeter.

3. The tensile strength of the cements as a measure of hydraulicity.

4. Determination of the water of hydration.

5. Boiling test.

6. Miscroscopic examination.

Perhaps the greatest confusion of opinion exists in regard to the relative hydraulic values of lime and magnesia and to illustrate the diversity of opinion existing on this topic, I shall quote somewhat at length as to various results obtained by a number of investigators.

In 1820, Fuchs, in working with several magnesia minerals such as talc, produced a good hydraulic cement. He found that magnesia burned at a lower temperature and was chemically more active than lime.

Heldt, another investigator, was not able to produce any hydraulic compounds from magnesia minerals and artificially prepared silicates.

Rivot again says, that magnesia behaves similarly to lime and forms with silica hydraulic compounds. He did not advise the use of magnesia cements, because the magnesia silicates and aluminates do not take up water as readily as the corresponding lime compounds.

Lieven, on the other hand, says that good cements cor-

responding to the formula $Mg\ SiO_3$ can be produced, which, when hydrated, possesses the formula $2(MgO\ SiO_2) .9\ H_2O$.

Beginning in the year 1887, a series of experiments was carried out by the Society of German Portland Cement Manufacturers, in which Dyckerhoff showed that magnesia in Portland cement, that is, in a vitrified cement promotes excessive expansion, and causes the cement to lose its property of being constant in volume. This result was vigorously disputed by A. Meyers and others, who claimed that the bad results were due to other deficiencies in the character of the cements tested.

In 1893, Kawalewsky made an extensive report on vitrified magnesia cements, which after ten years were still found to be constant in volume and which had shown high strength.

Golinelli, in 1895, reported a most carefully arranged series of tests with magnesium Portland cements, containing an average of 26 per cent. of MgO and corresponding to the ratio:

$$\frac{CaO + MgO}{SiO_2 + Al_2O_3 + Fe_2O_3} = 2.06.$$

The silica-alumina ratio maintained was 3. These cements possessed most excellent strength, and were entirely constant in volume. This investigator came to the conclusion that magnesia may well be substituted for the lime.

Prof. Tetmajer, perhaps the most widely known authority on the testing of cements, on examining two magnesia cements, found that they possessed a strength equal to that of Portland cement, and that they were constant in volume as tested by the standard boiling tests.

Spencer B. and W. B. Newberry, in 1897, arrived at the conclusion that magnesia, though possessing marked hydraulic properties when heated alone, yields no hydraulic products when heated with silica and alumina, and probably plays no part in the formation of cement. It is incapable of replacing lime in cement mixtures, the composition of which should be calculated on the basis of lime without regard to the magnesia present.

This great diversity of opinion can only be explained by the assumption that all these investigators worked under different conditions, neglecting the factors of temperature, mineralogical composition, fineness of grain, etc.

Evidence shows that many of our best American natural cements, such as the Rosendale, containing an average of 17 per cent. of magnesium carbonate, are equal in hydraulic value to those natural cements in which lime alone is present. Vitrified natural magnesia cements have already been tested some forty years ago by General Q. A. Gilmore, and were found to be highly hydraulic. Yet, some data show that if magnesia is present in a vitrified cement in a certain ratio to the lime, it is liable to cause trouble in hardening, owing to the fact that magnesia hydrates much more slowly than lime. The crystallization thus brought about by the magnesia falls into a period in which the lime silicates have already assumed a certain rigidity, thus giving rise to a tendency of the cement to increase in volume.

This seems to take place only under certain conditions, and hence many magnesia cements do not give any trouble at all. In the investigation of this subject, the difference existing between the natural magnesia cements burnt at a lower temperature, and magnesia cements burnt to vitrification should be duly considered, as this difference is both chemical and physical.

In the investigation of Portland cements, it is extremely important to study clays which, as we know, enter into the composition of many of our cements, and which often give rise to serious trouble in practical work. Cement chemists, as a rule, are perhaps inclined to study clays from the standpoint of the ultimate analysis almost exclusively without paying so much attention to their mineralogical character. We should remember that there are methods for the mineral examination of clays, as the method of Dr. Bischof, Professor Seger and the modified Lunge-Schochor method, adopted by the Ohio Geological Survey.

All clays may be said to be principally composed of three minerals: the clay substance proper, giving rise to plasticity and possessing the ideal composition Al_2O_3,

$2\,SiO_2$, $2\,H_2O$; feldspathic minerals remaining from incomplete decomposition of the original feldspar, and having the general formula RO, Al_2O_3 6, SiO_2; and quartz in various degrees of fineness.

These three minerals show marked differences in regard to their reactions with lime when subjected to heat. Clay substance, represented in its purest condition by washed kaolin or china clay, and in various degrees of impurity by the ordinary brick clays, reacts most readily with lime and is decomposed at very low temperatures, giving rise at first to a mono-silicate, which at a high temperature becomes a bi- and finally a poly-silicate. The first stage is the replacement of the combined water of the clay by the lime, a reaction which is most energetic, as is shown by the fact that clay substance decomposes calcium sulphate much more readily than silica at a lower temperature, and under but slightly reducing kiln conditions. After the expulsion of the chemical water, the union with more and more lime is a function of temperature.

The feldspathic minerals, though they do not combine with lime as energetically as clay substance, are not far behind in chemical activity, and owing to their high content of combined silica, they are an ideal basis for a cement. Beside introducing a desirable silica-alumina ratio, the minerals of the feldspathic type by means of their alkali content, lower the vitrification point of cements, thus decreasing the difficulty of burning.

The quantity of alkalies brought in, even if pure feldspar were used as the basis of cement, does not reach the point where it becomes injurious to the cement, for it must be remembered that combined alkali has an entirely different function from alkali brought in merely in the form of a carbonate. What Prof. Newberry says in regard to the addition of free alkali does not apply to a silicate like feldspar.

In this connection the interesting question of the production of white Portland cement might be mentioned. It seems to be an entirely feasible plan to produce a high grade white Portland cement by means of a white clay, high in

feldspathic matter, such as the Mt. Holly clay of Pennsylvania. The same end can be attained by preparing an artificial mixture of kaolin, feldspar and flint, which, of course, would be more expensive than the use of a naturally occuring easily fusible material. Several instances have come to the writer's notice, in which the production of a white cement was attempted simply by the use of kaolin and a lime bearing material. Since such a mixture, owing to the infusible nature of the kaolin, is extremely difficult to clinker, beside resulting in a highly aluminous cement, it is not surprising that the experiments proved failures.

The quartz unites with lime most reluctantly and only when finely ground, as has been shown by the writer in previous work, and hence the entire raw grinding process must be directed towards grinding the free quartz so fine that it will combine in the kiln with the desired amount of lime; but this has its commercial draw back. Experiments designed to show how far the grinding must be carried on in a tube mill, so as to produce a good cement from clays containing certain amounts of more or less coarse quartz are urgently needed, and would prove very valuable. Also, it would be exceedingly instructive to know just what size of quartz is absolutely necessary for combination with the lime in the rotary kiln. By knowing this, it might be possible to decrease the lime content, allowing a certain excess of inert silica, and preventing the presence of free lime. The problem certainly has a decided commercial interest.

This also brings us to the question of using quartz introduced into the cement mixture in the shape of sand stone. There is no reason why an addition of quartz to highly aluminous clays should not be feasible and practicable, though in this case it would be necessary to use a set of separate crushing and grinding machinery, which would grind the sand stone to quite a fine powder before it is added to the clay and lime materials. Since the amount of quartz thus required is comparatively small, it would seem that the expense of the extra grinding is not prohibitive.

Some interesting data could be collected by studying the residue insoluble in HCl and Na_2CO_3 solution of various

Portland cements, made from different raw materials; this residue, of course, consists practically of inert silica and carbon, and is bound to tell a tale of the sufficiency of grinding and combination.

Beside the mineralogical consideration of the clays used in cement making, the general chemical question of the best ratio between silica and alumina is one which deserves thorough attention, and would amply repay the labor of determining it. All who are aequainted with the manufacture of Portland cement, realize that clays too high in alumina produce cements apt to show very disagreeable and dangerous properties.

In the United States about three general types of grinding machinery are in use for this grinding of the raw and burnt cement. It is the object of grinding the raw mixture to establish as intimate a molecular contact as practicable, thus bringing about as complete a chemical reaction as possible. On the other hand, the clinker must be ground as finely as possible in order that the highest cementing power may be produced, and it is well known that the higher the percentage of the very finest particles in a cement, the greater will be the strength and bonding power. The amount of this extremely fine powder can be roughly estimated by the use of sieves, but this kind of test does not offer a sufficiently accurate basis of comparison. We can, however, arrive at a satisfactory determination by means of a mechanical separation of various sizes of particles, arbitrarily fixed. The most convenient method is that of suspension, in which the powder is allowed to settle a given length of time in beakers containing water if the raw mixture is to be examined, and 95 per cent. alcohol if a cement is to be subjected to the test. The sizes thus obtained are measured quite readily by means of a micrometer slide attached to a microscope. In this manner the true efficiency of a grinding machine can be determined, for the apparatus producing the greatest amount of the finest particles per unit of power is the most desirable machine.

Finally, the writer would like to allude to a most important economic problem, namely, the determination of the

suitability of the various coals for the burning of Portland cement in the rotary kiln, a question involving elaborate experiments and a great outlay, but amply justified by the importance of the matter at issue. The question which coals are and which are not suitable for this purpose, comprises besides the strictly thermal questions of calorific power, calorific intensity, inflammability, also the investigation of the effects produced by the sulphur in the coal.

In conclusion, it might be said that a number of the investigations outlined are now being carried on by the Ohio Geological Survey, and are being pushed towards completion as rapidly as possible. It is hoped by the Survey that the work may contribute some definite knowledge to the store of information already available, and that the American manufacturers may be induced to adopt the liberal policy, so splendidly manifested by the Society of German Portland Cement Manufacturers, to whom the world is indebted for so much scientific information. This body of manufacturers, by contributing large sums of money for the establishment of a fine laboratory, and the carrying on of research work for the benefit of its members, as well as by doing independent individual work, has accomplished results unexcelled in the annals of any manufacturer's organization. There is no reason whatever why the American Portland cement manufacturers should not accomplish as much or more, by simply co-operating along these lines. The benefits thus reaped would be of such magnitude, that the slight expenditure of time and money necessary would be positively insignificant.

NOTES ON THE DEVELOPMENT OF GREENS FROM CUPRIC OXIDE IN GLAZES.

BY

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The notes presented in this paper do not cover the subject as fully as I had intended, as I found my time too limited to undertake a larger investigation and have it ready for this meeting.

The experiments have been confined to the following basic oxides; lime, potash, soda, lead, barium, zinc and magnesia, displacing each other in the formulæ in regular order, so that the changes occuring, and the effects upon cupric oxide could be readily noted.

Green glazes produced with copper are subject to so many changes when under fire, that it becomes very necessary to use every care, both in the making and burning of the glaze. The least variation of the temperature or the method of firing the kiln, will change the color, varying from a bright green to a brown or yellow shade.

The volatility of copper also causes considerable trouble; the fumes are absorbed by the sagger, and are liberated when again placed in the kiln, tinting the ware in the sagger; a white glaze showing quite strongly the effect by absorption of the green color. To avoid difficulties of this kind it becomes necessary to have separate saggers for colors containing copper oxide. Where it is desired to produce transparent glazes of a green color at ordinary kiln temperatures, it is necessary to use oxide of copper; the other mineral oxides produce greens which are more or less opaque.

For the purpose of ascertaining the action of the basic oxides, the change of color and the fluxing produced in combination with oxide of copper, and a correction, if possible, of some of these troubles, a line of experiments was decided upon as follows:

First. The effect of the different basic oxides in combination, and their action in developing the green color from a constant content of cupric oxide.

Second. Increase of alumina content, keeping the silica content as a mono-silicate or bi-oxygen ratio.

Third. Increase of silica content, with the alumina content remaining constant.

Fourth. Replacement of silica content with an equivalent proportion of boric acid, retaining the same acidity with an increase in oxygen ratio.

Fifth. Increase of the alumina content with silica content remaining constant, thus producing a reduction of the acidity.

Sixth. Development under same conditions of fire and temperature on a silicious dust-pressed body, and an earthenware plastic body.

Seventh. Experiments to be made at cone 02 and 2, showing the change, if any, caused by the increased temperature.

To lessen the work as much as possible, at the same time to retain close enough interchange of the bases as outlined in the first proposition, 0.1 equivalent of cupric oxide was decided to be sufficient copper strength to show the changes, leaving 0.9 equivalent to make up the RO elements for all of the experiments.

This was done by making a change of .15 equivalent in each combination, beginning, as you will note, by referring to experiments one to six, at .45 equivalents each of two elements, down to .15 equivalent each of six elements, as seen in Nos. 91 to 97; being a gradual replacement and interchange of the basic oxides, and final elimination of lime in No. 97. The Al_2O_3 and SiO_2 content was the same in all of these experiments.

In the series of experiments Nos. 98 to 137, in which there is an increase of alumina, retaining the bi-oxygen ratio; increase of silica; introduction of boric acid; an increase of alumina, keeping constant content of silica; the RO elements were kept the same, to enable an easy and just comparison with each series.

The following table of formulæ gives a complete view of the glazes under consideration:

No.	CuO	CaO	K_2O	Na_2O	PbO	BaO	ZnO	MgO	Al_2O_3	SiO_2	B_2O_3
1	.10	.45	.45	....	...	....	.	....	.20	1.60	....
2	.10	.45	...	.45	...	....	....	....	.20	1.60	....
3	.10	.45	...	....	.45	....	....	....	.20	1.60	....
4	.10	.45	...	....	...	.45	.. .	....	.20	1.60	....
5	.10	.45	...	....	...	....	.45	....	.20	1.60	....
6	.10	.45	...	....	...	....	....	.45	.20	1.60	....
7	.10	.45	.30	.15	...	....	....	....	.20	1 60	....
8	.10	.45	.30	....	.15	....	....	...	.20	1.60	....
9	.10	.45	.30	....	...	.15	....	....	.20	1.60	....
10	.10	.45	.30	....	...	....	.15	....	.20	1.60	....
11	.10	.45	.30	....	...	....	....	.15	.20	1.60	....
12	.10	.45	.15	.30	...	....	....	....	.20	1.60	....
13	.10	.45	...	.30	.15	....	....	....	.20	1.60	....
14	.10	.45	...	.30	...	.15	....	....	.20	1.60	....
15	.10	.45	...	.30	...	....	.15	....	.20	1.60	....
16	.10	.45	...	.30	...	....	....	.15	.20	1.60	....
17	.10	.45	...	.15	.30	....	....	....	.20	1.60	....
18	.10	.45	.15	....	.30	...	....	....	.20	1.60	....
19	.10	.45	...	....	.30	.15	....	....	.20	1.60	....
20	.10	.45	...	....	.30	....	.15	....	.20	1.60	....
21	.10	.45	...	....	.30	...	....	.15	.20	1.60	....
22	.10	.45	...	....	.15	.30	....	....	.20	1.60	....
23	.10	.45	...	.15	...	.30	....	....	.20	1.60	....
24	.10	.45	.15	....	...	.30	....	....	.20	1.60	....
25	.10	.45	...	....	...	.30	.15	....	.20	1.60	. ..
26	.10	.45	...	....	...	.30	....	.15	.20	1.60	....
27	.10	.45	...	....	...	.15	.30	....	.20	1.60	....
28	.10	.45	...	....	.15	....	.30	....	.20	1.60	....
29	.10	.45	...	.15	...	....	.30	....	.20	1.60	....
30	.10	.45	.15	....	...	....	.30	....	.20	1.60	....
31	.10	.45	...	....	...	....	.30	.15	.20	1.60	....
32	.10	.45	...	....	...	....	.15	.30	.20	1.60	....
33	.10	.45	...	....	...	.15	....	.30	.20	1.60	....
34	.10	.45	...	....	.15	....	....	.30	.20	1.60	....
35	.10	.45	...	.15	...	....	....	.30	.20	1.60	....
36	.10	.45	.15	....	...	....	....	.30	.20	1.60	....
37	.10	.30	.30	.30	...	....	....	....	.20	1.60	....
38	.10	.30	.30	....	.30	....	....	....	.20	1.60	....
39	.10	.30	.30	....	...	.30	.. .	....	.20	1.60	....
40	.10	.30	.30	....	...	....	.30	....	.20	1.60	....
41	.10	.30	.30	....	...	....	....	.30	.20	1.60	....

No.	CuO	CaO	K_2O	Na_2O	PbO	BaO	ZnO	MgO	Al_2O_3	SiO_2	B_2O_3
42	.10	.30	...	.30	.30	....	....	....	.20	1.60	....
43	.10	.30	...	.30	...	.30	....	....	.20	1.60	....
44	.10	.30	...	.30	...	....	.30	....	.20	1.60	...
45	.10	.30	...	.30	...	....	....	.30	.20	1.60	....
46	.10	.30	...	....	.30	.30	....	...	.20	1.60	....
47	.10	.30	...	....	.80	....	.30	....	.20	1.60	....
48	.10	.30	...	...	.30	....	....	.30	.20	1.60	....
49	.10	.30	...	....	...	.30	.30	....	.20	1.60	....
50	.10	.30	...	....	...	.30	....	.30	.20	1.60	....
51	.10	.30	...	....	...	....	.30	.30	.20	1.60	....
52	.10	.30	.30	.15	.15	....	...	....	.20	1.60	...
53	.10	.30	.30	.15	...	.15	....	....	.20	1.60	....
54	.10	.30	.30	.15	...	....	.15	....	.20	1.60	...
55	.10	.30	.30	.15	...	....	....	.15	.20	1.60	....
56	.10	.30	.30	....	.15	.15	....	....	.20	1.60	....
57	.10	.30	.30	....	.15	....	.15	....	.20	1.60	....
58	.10	.30	.30	....	.15	....	....	.15	.20	1.60	....
59	.10	.30	.30	....	...	.15	.15	....	.20	1.60	....
60	.10	.30	.30	....	...	.15	....	.15	.20	1.60	....
61	.10	.30	.30	....	...	....	.15	.15	.20	1.60	....
62	.10	.30	...	.30	.15	.15	....	....	.20	1.60	....
63	.10	.30	...	.30	.15	....	.15	....	.20	1.60	....
64	.10	.30	...	.30	.15	....	....	.15	.20	1.60	...
65	.10	.30	.15	.30	.15	....	....	....	.20	1.60	....
66	.10	.30	...	.30	...	.15	.15	....	.20	1.60	....
67	.10	.30	...	.30	...	.15	....	.15	.20	1.60	....
68	.10	.30	.15	.30	...	.15	....	....	.20	1.60	...
69	.10	.30	...	.30	...	....	.15	.15	.20	1.60	....
70	.10	.30	.15	.30	...	....	.15	....	.20	1.60	....
71	.10	.30	.15	.30	...	....	....	.15	.20	1.60	....
72	.10	.30	...	....	.30	.15	.15	....	.20	1.60	....
73	.10	.30	...	....	.30	.15	....	.15	.20	1.60	....
74	.10	.30	...	.15	.30	.15	....	....	.20	1.60	....
75	.10	.30	.15	....	.30	.15	....	....	.26	1.60	....

No.	CuO	CaO	K_2O	Na_2O	PbO	BaO	ZnO	MgO	Al_2O_3	SiO_2	B_2O_3
76	.10	.30	...	....	.30	....	.15	.15	.20	1.60	....
77	.10	.30	...	.15	.30	....	.15	....	.20	1.60	....
78	.10	.30	.15	....	.30	....	.15	....	.20	1·60	....
78-A	.10	.30	...	.15	.30	....	....	.15	.20	1.60	....
78-B	.10	.30	.15	....	.30	....	...	.15	.20	1.60	....
79	.10	.30	...	....	...	.30	.15	.15	.20	1.60	....
80	.10	.30	...	....	.15	.30	.15	....	.20	1.60	....
81	.10	.30	...	.15	...	.30	.15	....	.20	1.60	....
82	.10	.30	.15	....	...	.30	.15	....	.20	1.60	....
82-A	.10	.30	...	....	.15	.30	....	.15	.20	1.60	....
82-B	.10	.30	...	.15	...	.30	....	.15	.20	1.60	....
82-C	.10	.30	.15	....	...	.30	....	.15	.20	1.60	....
83	.10	.30	...	....	...	.15	.30	.15	.20	1.60	....
84	.10	.30	...	....	.15	....	.30	.15	.20	1.60	....
85	.10	.30	...	.15	...	....	.30	.15	.20	1.60	....
86	.10	.30	.15	....	...	....	.30	.15	.20	1.60	....
87	.10	.30	...	...	...	.15	.15	.30	.20	1.60	....
88	.10	.30	...	....	.15	....	.15	.30	.20	1.60	....
89	.10	.30	...	.15	...	....	.15	.30	.20	1.60	....
90	.10	.30	.15	....	...	....	.15	.30	.20	1.60	....
91	.10	.15	...	.15	.15	.15	.15	.15	.20	1.60	....
92	.10	.15	.15	....	.15	.15	.15	.15	.20	1.60	....
93	.10	.15	.15	.15	...	.15	.15	.15	.20	1.60	....
94	.10	.15	.15	.15	.15	....	.15	.15	.20	1.60	....
95	.10	.15	.15	.15	.15	.15	....	.15	.20	1.60	....
96	.10	.15	.15	.15	.15	.15	.15	....	.20	1.60	....
97	.10	...	.15	.15	.15	.15	.15	.15	.20	1.60	....
98	.10	.30	.15	....	.30	....	.15	....	...	1.00	....
99	.10	.30	.15	....	.30	....	.15	....	.05	1.15	....
100	.10	.30	.15	....	.30	....	.15	....	.10	1.30	....
101	.10	.30	.15	....	.30	....	.15	....	.15	1.45	....
102	.10	.30	.15	...	.30	...	.15	....	.20	1.60	....
103	.10	.30	.15	....	.30	....	.15	....	.25	1.75	....
104	.10	.30	.15	....	.30	....	.15	....	.30	1.90	....
105	.10	.30	.15	....	.30	....	.15	....	.35	2.05	....
106	.10	.30	.15	...	.30	....	.15	....	.40	2.20	....
107	.10	.30	.15	....	.30	....	.15	....	.20	1.00	....
108	.10	.30	.15	....	.30	....	.15	....	.20	1.25	....
109	.10	.30	.15	....	.30	....	.15	....	.20	1.50	....
110	.10	.30	.15	....	.30	...	.15	....	.20	1.75	....
111	.10	.30	.15	....	.30	...	.15	....	.20	2.00	....
112	.10	.30	.15	....	.30	....	.15	....	.20	2.25	....

No.	CuO	CaO	K_2O	Na_2O	PbO	BaO	ZnO	MgO	Al_2O_3	SiO_2	B_2O_3
113	.10	.30	.15	....	.30	....	.15	....	.20	2.50	....
114	.10	.30	.15	....	.30	....	.15	....	.20	2.75	....
115	.10	.30	.15	....	.30	....	.15	....	.20	3.00	....
116	.10	.30	.15	....	.30	....	.15	....	.20	3.25	....
117	.10	.30	.15	....	.30	....	.15	....	.20	3.50	....
118	.10	.30	.15	....	.30	....	.15	....	.20	1.75	....
119	.10	.30	.15	....	.30	....	.15	....	.20	1.70	.05
120	.10	.30	.15	....	.30	....	.15	....	.20	1.65	.10
121	.10	.30	.15	....	.30	....	.15	....	.20	1.60	.15
122	.10	.30	.15	....	.30	....	.15	....	.20	1.55	.20
123	.10	.30	.15	....	.30	....	.15	....	.20	1.50	.25
124	.10	.30	.15	....	.30	....	.15	....	.20	1.45	.30
125	.10	.30	.15	....	.30	....	.15	....	.20	1.40	.35
126	.10	.30	.15	....	.30		.15	....	.20	1.35	.40
127	.10	.30	.15	....	.30	....	.15	....	.20	1.30	.45
128	.10	.30	.15	....	.30	....	.15	....	.20	1.25	.50
129	.10	.30	.15	...	.30	....	.15	....	.10	1.60	....
130	.10	.30	.15	....	.30	....	.15	....	.15	1.60	....
131	.10	.30	.15	...	.30	....	.15	....	.20	1.60	....
132	.10	.30	.15	....	.30	....	.15	....	.25	1.60	....
133	.10	.30	.15	....	.30	....	.15	....	.30	1.60	....
134	.10	.30	.15	....	.30	....	.15	....	.35	1.60	....
135	.10	.30	.15	....	.30	....	.15	....	.40	1.60	....
136	.10	30	.15	....	.30	....	.15	....	.45	1.60	....
137	.10	.30	.15	....	.30	....	.15	....	.50	1.60	....

In these experiments the K_2O was obtained from pure carbonate potash, Na_2O from crystal carbonate of soda, PbO and BaO from the carbonates and ZnO and MgO from the oxides. Al_2O_3 was obtained entirely from clay, .05 equivalent being raw clay and the balance calcined clay.

The carbonates of potash, soda and barium, and boric acid were fritted, while the other elements were used without fritting, as was the oxide of copper.

The glazes were all carefully prepared and passed through a brass lawn of 200 meshes to the inch. The tiles were glazed and placed together in the same kiln and fired at cone 02. A second lot was placed in an other kiln and fired at cone 2.

THE RESULTS.

The benefit of these experiments can only be gained by a careful examination of the samples. No words can convey the numberless delicate shading of the tints produced. Nevertheless, the pen can describe a few of the coarser or more obvious distinctions, which are given below:

In glazes 1 to 6, the RO is composed of .45 equivalent of CaO and .45 equivalent of one of the other elements. this being the highest quantity of any of the basic oxides thought advisable in this line of experiments.

No. 3, containing PbO, was the only one showing satisfactory glaze results; it developed a very dark green, both at cone 02 and 2, the former having considerable scum over the surface, with well defined crystals around the edges, while the latter was a very clear glaze with a few small crystalline spots on the surface.

The other glazes in this series were immature at both cone 02 and 2, each base, however, showing different action in developing the copper, as well as fusibility. K_2O gave a yellowish green, while the Na_2O leaned to the gray; BaO developed in its semi-vitreous state at cone 02 a turquois green, but lost the color at the higher heat, changing to a blackish green; the ZnO at the lower heat had a chrome green shade, changing at cone 2 to a darker color. Their fusibility was in the order named: PbO, Na_2O, ZnO, K_2O and BaO; the MgO was infusible, the CuO having passed

into the body, leaving the glaze without any color and peeled from the body.

The details of this series has been given more fully than will be possible with the others, to show the action of the different basic oxides when in combination with CaO, and comparison when combined with two or more of the basic oxides.

In glazes 7 to 11 where the K_2O has been reduced to .30 equivalents, and combined with .15 equivalents of one of the other bases, the introduction of the third base gives an entirely different color effect. The zinc glaze, No. 10, is the only one showing a fully developed glaze at cone 2. It had a light bluish iridescence, while at cone 02 it was more of a chrome shade with soft velvety matt effect.

BaO, No. 9, gives a grayish green matt glaze at cone 2, while PbO, No. 8, is a dark blackish green color, iridescent crystaline surface with apparently a clear glaze underneath at cone 2. MgO, No. 11, shows some fusibility at cone 2, with good color effect.

In the glazes 12 to 16, where the .30 equivalents K_2O has been replaced by Na_2O, all show more fusibility than the former series. ZnO, No. 15, is, however, the only clear glaze at cone 2, as it was in the previous series, and a light sea green shade; at cone 02 a dark brown matt glaze was developed.

By the introduction of .30 equivalents of PbO in glazes 17 to 21, a line of more fusible glazes are obtained, with entirely different results from the preceding experiments. The ZnO member—No. 20—is a beautiful clear green, the K_2O shows most fusibility, and the Na_2O has many small crystals on the surface.

The BaO glaze, No. 19, is covered with a scum, showing some tendency to crystalize and is the only one in this series that shows any crazing. At cone 02 this series is thoroughly fused, but the heat is not sufficient to fully develop the glazes.

There is very little variation in the color effect in this series; the increased content of PbO seems to negative the

action of the other bases on copper which is very noticeable in comparing No. 18 with No. 8, or No. 17 with No. 13.

BaO in No. 22 to No. 26, does not give the fusible qualities expected from it, as none of the glazes have cleared. K_2O in No. 24 seems to excite the fluxing qualities of BaO more than the other bases.

In the series containing .30 equivalents ZnO, No. 27 to No. 31, the one with BaO, No. 27, is more fusible than the barium zinc combination, No. 25, which contains a larger quantity BaO. The increase of ZnO excites the fluxing, while the reverse is the case with PbO, No. 28, when compared with No. 20. The most fusible of this series is the Na_2O member, No. 20, which gives a very dark clear grass green, deepening and changing the color when compared with No. 15 which is much lighter and more of a turquoise, while the one with K_2O, No. 30, has a bluish cast more of a sea green, with some fine crystals on the surface.

Nos. 27 and 28 at cone 02 are matt glazes, the former showing some signs of crystalizing, while the latter produces a very soft velvety matt surface of a bronze green color. No. 29 at cone 02 gives a semi-matt glaze, of a chrome-green color.

In the glazes No. 31 to No. 36, containing .30 equivalents MgO, there is no signs of fusion at cone 02, the glaze cracking and peeling from the body, while at cone 2, No. 34, with PbO, is vitrified with dull surface, No. 36 and No. 35 being next in order of fusibility.

The order of fusibility with .15 equivalent of MgO is No. 21, No. 16, No. 11, No. 26, and No. 31, containing .45 Eq. CaO, and .30 Eq. PbO, Na_2O, K_2O, BaO, and ZnO respectively.

In all of the glazes from No. 1 to 36, containing .45 equivalent CaO, there are none of practical use at cone 02, but several at cone 2; No. 20 being a very good glaze, dark green with slight yellow cast, while at cone 02 there are several excellent dull or matt glazes, as above mentioned.

In considering glazes 37 to 41, you will note the first reduction in CaO content to .30 equivalent, dividing the other bases into .30 equivalent each.

A reduction of CaO and the addition of .15 equivalent of one of the other bases, when compared with series No. 7 to No. 11 shows increased fusibility, except in No. 41, MgO; No. 40 containing ZnO gives a bluish opaque color at cone 2 while at cone 02 a semi-mat blue-green glaze. In No. 39 we have a peculiar black-green matt surface at both cone 2 and 02, with very fine crystals covering the surface at cone 2.

In the soda Series, No. 42 to No. 45, there is an increased fusibility when compared with No. 12 to No. 16, with the exception of No. 45, MgO. The whole series is more fusible than the one containing K_2O. The color in No. 44 at cone 02 gives a gray-green matt surface and loses the blue color produced by K_2O in No. 40.

In Nos. 46 to 51, which closes the .30 equivalent series, are some interesting effects. In No. 47 the increase of zinc does not perceptibly affect the color or fusibility in comparison with No. 20, except that in the former, small floculent spots appear suspended in the glaze. No. 49 has qualities worthy of further investigation, producing a semi-glossy surface of very good dark green. Nos. 48 to 51 are matt surfaces, the first a yellow-green, while the other is a gray-green.

In the next series of experiments, a fourth element is introduced in the RO, with increased fusibility and change of color all through the series; but I will not attempt to give a detailed analysis, only calling your attention to a few of the most marked changes. Again, the larger content of Na_2O over K_2O shows in a marked degree more fusibility and decided difference in color effect, as seen by comparing No. 53 and No. 54 with No. 68 and No. 70 at cone 2.

Nos. 58, 59, 61, 69 and 78B at cone 2 are dull on semi-dull surfaces, the colors being entirely different, varying from a gray to a blue and brownish-green. The surface of No. 69 is covered with fine gray needle crystals, with a darker green in the body glaze, and is worthy of further consideration as are all the others.

The Series No. 70 to No. 82, containing .30 equivalents

of barium produces at cone 2, some dull effects that can be followed to advantage in some further experiments.

No. 85 is a fully developed, very dark brilliant green glaze at cone 2, while at cone 02 shows little signs of fusion.

The first combination with MgO, giving satisfactory results, is the one with lead and zinc, No. 76, giving a dark, clear green glaze, but practically the same color as the ones with K_2O and Na_2O content, No. 77 and No. 78, indicating that MgO has no peculiar action in producing copper greens.

In the series containing an equal division of the RO elements, the results were not as anticipated, as more fusible glazes were expected. The only ones showing any tendency to a clear glaze, were Nos. 91, 92, 94 and 96, at cone 2, No. 94 being a fully developed dark green glaze. No. 97, the only one in the entire series without CaO, gives every indication of a good glaze at a little higher heat, and does not indicate that lime has any decided effect in developing copper greens.

In Nos. 98 to 106 is an increase of Al_2O_3 with corresponding increase of SiO_2, keeping the bi-oxygen ratio, beginning at a very low SiO_2 content without any Al_2O_3 and increasing by .05 equivalent up to .40 equivalent, and in Nos. 129 to 137 is an increase of Al_2O_3, without any change in SiO_2 content, reducing from an oxygen ratio of 2.46 to 1.28.

The effect of an increase of Al_2O_3 is very marked, the color gradually changing from a bright emerald green to a very deep green in No. 101 and then gradually getting lighter to a yellow green with fairly satisfactory glazes at cone 2 up to the one containing .30 equivalent of Al_2O_3, No. 105, and at cone 02, up to .20 equivalent Al_2O_3, No. 102, with very slight variation of color between the two temperatures on the dust pressed body, while on the earthenware body at cone 02, the glazes are better developed, but show a tendency to crazing.

No. 98 without any alumina, is a very good glaze at cone 2, while at cone 02, small crystals are seen along the

edges and on the surface of the glaze; No. 106 begins to show a flaky crystalline effect from the increase of Al_2O_3.

The same effect of producing a yellow green is also very noticeable in Series Nos. 129 to 137, giving a dark green up to No. 131, when the yellow begins to show its effect on the color, by the increase of Al_2O_3, but not so much as in the other series; .10 equivalent at cone 02 and .25 equivalent at cone 2 seems to be the limit of Al_2O_3 in producing glazes with SiO_2 content of 1.60 equivalent. The glazes beyond these qualities having a matt effect with a soft velvety surface on the higher Al_2O_3 content at cone 02 and cone 2; .40 equivalent produces the best mat surface at cone 02 and .50 equivalent at cone 2.

This line of experiments on the earthenware body are more fusible, without any change in color.

With the increase of silica, maintaining alumina constant, Series Nos. 107 to 117, we have good glazes from Nos. 108 to 113 at cone 2, and fairly good at cone 02, the latter showing some tendency to creep, which no doubt can be corrected by a mechanical change in the mixing of the glaze. The higher silica glazes of this series are in various stages of devitrification, the first indication appearing in No. 111, but all of them produce a rough texture.

There is a decided difference between Nos. 107 and 108, .25 equivalent of SiO_2 changing the glaze from a matt to practically a clear glaze at cone 02, and at cone 2 to a beautiful shade of green with a little tendency to crazing. No. 107 at cone 2 has lost the matt, changing into a fully vitrified glaze, covered with small crystals. The texture of the matt effect in No. 107 is very much the same as produced by high Al_2O_3 content, and compares very closely to No. 133 in surface, but not in color. Increased SiO_2 content has no perceptable change in color at either temperature.

The earthenware body in this series gives about the same degree of fusion at cone 02 as the dust pressed body does at cone 2, but no difference in the color.

The boric acid series, Nos. 119 to 128, gives a good line of glazes at cone 2 with very little change in color, but showing some signs of bleaching to a lighter color; but at

cone 02 on the dust pressed body, the lower series of B_2O_3 are somewhat crystalized and looks very much like the beginning of divitrification, decreasing as the B_2O_3 increases; Nos. 122 to 128 are clear glazes, the higher content giving a brighter green. On the earthenware body, the glazes are all good, but there is considerable change in color between cones 02 and 2, the latter giving an entirely different quality of green.

The separating and creeping of many of these glazes, can be corrected by changing the mechanical mixing, either in the glaze or the making of the fritt, but in this line of experiments a uniform method was used to get exact comparison of the peculiar action of the RO elements when in combination with oxide copper.

The deductions to be derived from this line of experiments are such as to excite the desire for a further investigation, and makes me hesitate to place before you what I consider is incomplete; and in doing so, I sincerely hope my results will be the means of starting some one on a similar and more complete analysis of the development of greens from cupric oxide. I have not had the time to verify any of these experiments, and give them to you merely as first results.

The alumina content of .20 equivalent in Nos. 1 to 97 was decided upon, after several preliminary trials, as the best content for this investigation. A different proportion might have changed some of the results, producing more satisfactory glazes, but without giving the same comparison.

From these experiments, the indications are that CaO can be used in any quantity found necessary in producing a satisfactory glaze, without affecting the color produced from copper. But with the introduction of K_2O, the color is changed to a yellowish tint; and and when in combination with either Na_2O or PbO, the K_2O can not exceed .15 equivalent without affecting the color; but ZnO controls the green color when content of K_2O is as high as .30 equivalent: the color becomes very much deeper as the K_2O decreases and the ZnO is increased. This same effect of

deepening the color is produced when ZnO is combined with Na_2O, but with an entire change of color.

The same can be said of the zinc-barium glaze, the color getting stronger when the ZnO is increased to .30 equivalents and BaO decreased to .15 equivalents. BaO is more fusible when in combination with ZnO than with Na_2O, producing a better working glaze. The barium-zinc glaze has decidedly a blue shade when combined with either Na_2O or K_2O, but with PbO has more of a chrome green color. BaO when with .15 equivalents of MgO produces a color very different from that produced with PbO.

ZnO when in combination with either K_2O or Na_2O and not exceeding .15 equivalents gives a light clear glaze leaning to the blue; but when the ZnO is increased to .30 equivalents, and the CaO reduced to .30 equivalents, the one with K_2O produces a lighter shade, decidedly blue and opaque; while the one with Na_2O changes color more to the brown, but gives a clear glaze.

ZnO has a very decided action in producing colors in both clear and matt glazes; .15 equivalent shows a more marked effect than .15 of any of the other bases. ZnO can be used to advantage with all basic oxides, making the color more brilliant when in combination with PbO, and giving most beautiful and varied shades from copper when in other combinations. I am not prepared to say conclusively that ZnO has a strong tendency to excite the fluxing with cupric oxide, but every indication points to such action.

.30 equivalent of PbO when in combination with .45 equivalents of CaO and .15 equivalents of one of the other bases, controls completely the color, producing a clear deep green; but loses this effect when reduced to .15 equivalents: with the reduction of the CaO to .30 equivalents, the PbO does not have the same power, the color being modified according to the other base introduced.

Replacement of CaO with MgO retards fusion, without changing the color, except in the one with PbO, which is a very much lighter shade of green; and more of a gray-green when the MgO is increased.

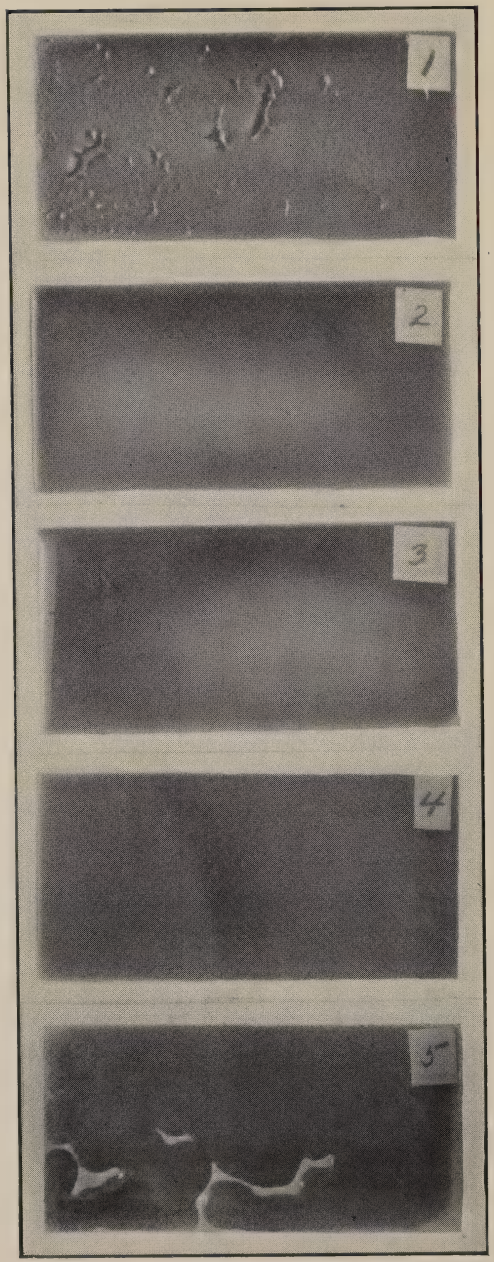
With the introduction of boric acid, replacing equiva-

lent contents of silica, we have a line of colors showing but slight changes, the largest B_2O_3 content being a little lighter but more brilliant green; while the SiO_2 content in all proportions seem to give about the same shade; but with alumina the content must be kept down to secure a pure green color.

In summing up the facts demonstrated from these experiments, SiO_2 and B_2O_3 can be used in any desired content, while Al_2O_3 should not exceed .25 equivalents, unless the shade of green desired is to be of yellow tint; while in the RO elements, not over .30 equivalents should be used of any one base for best effects.

I have endeavored to deduce something from these experiments that will prove interesting and of advantage, but fully realize my lack of descriptive power to convey intelligently to you the color changes. I am fully convinced there is but on way for you to get any real benefit from this paper, and that is for you to make a similar line of experiments, and I certainly cannot urge you too strongly to do so, assuring you that the labor connected therewith will be fully repaid by the interesting study you will have when completed.

NOTE BY THE EDITOR:—The effort has been made in the following pages to reproduce the color series which Mr. Walker exhibited while reading his paper. The effort has been only partly snccessful, as it only shows the color effects by variations of shade, and cannot bring out the marvelous differences of quality of color. However, the plates in connection with the descriptive text will help the careful student to gain some impressions which would otherwise be wholly lost.


1
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5

Series Fired at Cone 2.

1. *Composition.* 0.10 CuO 0.45 CaO 0.45 K_2O, 0.20 Al_2O_3 1.60 SiO_2.

An imperfectly fused, matt glaze, with signs of glossy surface around edges. Not fluid enough to heal over the defects formed during shrinkage. Color, dirty yellowish-green around edges, which show dark in the cut. In the center, the color shades into a steel gray, which reflects light and appears lighter in the cut. No promise for any practical purpose.

2. *Composition.* 0.10 CuO 0.45 CaO 0.45 Na_2O, 0.20 Al_2O_3 1.60 SiO_2.

A much better fused glaze, smooth to the touch. It is not a good matt, but is equally removed from a glossy surface. Shows few lines, indicating where shrinkage cracks formed and subsequently mended. Color, apple-green around edges, which show dark in cut, but shading into a dark grayish-black color in center, which appears lighter in the cut Not attractive.

3. *Composition.* 0.10 CuO 0.45 CaO 0.45 PbO, 0.20 Al_2O_3 1.60 SiO_2.

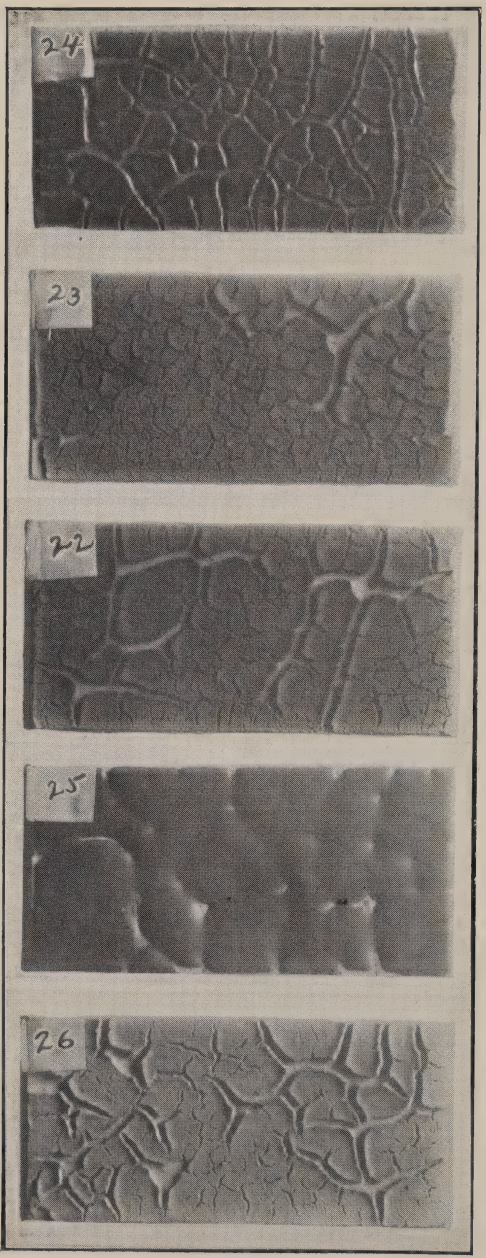
A brilliant perfectly fused glaze of high finish. A few smal blotches of some undissolved matter, seen faintly in the upper left-hand corner of the cut. Color, a brilliant clear copper-green, apparently equally removed from the blue or yellow tints. Contrast is due to the difference in depth of glaze, which makes the color very dense in left-hand upper corner. Could be used, as far as color or surface is concerned, for any purpose.

4. *Composition.* 0.10 CuO 0.45 CaO 0.45 ZuO, 020 Al_2O_3 1.60 SiO_2

A semi-crystalline matt, whose imperfectly obliterated shrinkage lines form a rather coarse net work, giving a peculiar and rather pleasing curdy appearance. Surface feels much less smooth than No. 2 and smoother than No. 1. Color is an opaque blue-green, almost of the tint known as "robin's egg" blue. A glaze which invites further development.

5. *Composition.* 0.10 CuO 0.45 CaO 0.45 ZuO, 0.20 Al_2O_3 1.60 SiO_2.

An imperfectly fused glaze, which has not flowed enough to cover all of its shrinkage cracks, though it has covered some. Surface is matt, mostly, but in a few patches, especially on left hand end, the scum breaks away and exposes a glossy surface. The scum or matt surface gives this tile a grayish-green cast, which appears clear and darker in color where the film is broken away. Not a workable glaze at present.


24
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Series Fired at Cone 02.

0.20 Al_2O_3, 1.60 SiO_2 throughout series.

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24. *Composition.* 0 10 CuO 0.45 CaO 0.30 BaO, 0.15 K_2O.

A crackled, shrunken mass, just beginning to soften and round off the edges and corners. Color, light bluish-green around edges of tile, but a strong dark chrome green in all the central portion of tile.

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23. *Composition.* 0.10 CuO 0.45 CaO 0.30 BaO, 0.15 Na_2O.

A much dryer, less vitreous mass than 24, cracks numerous and edges sharp. Would not have fused for a number of cones higher. Color faded out to a light blue around edges. In central portion, the color is a dark neutral tint, or slate blue, with a slightly purplish cast. No likelihood of this glaze becoming useful

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22. *Composition.* 0.10 CuO 0.45 CaO 0.30 PaO, 0.15 PbO.

A still less fused mass, shrunken and vitrified and crossed by numerous deep, sharp edged cracks. Volatilization has bleached edges to a clear light blue-green, but center is a much darker shade of the same color, not unlike No. 23, but bluer. No utility. This slab is remarkable, in view of the high fluxing value of lead and its small effect here, compared to fluxes which are elsewhere less active.

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25. *Composition.* 0.10 CuO 0.45 CaO 0.30 BaO, 0.15 ZnO.

A smooth, satin-finish mass, imperfectly fluid, not wholly obliterating the shrinkage cracks, through which the body sometimes shows. Texture wonderfully fine. Color, a beautiful dark chrome-green enamel, marked with black lines where cracks have been healed over. If a little more fluid, so as to cover the body wholly, this would make a fascinating surface finish for art ware.

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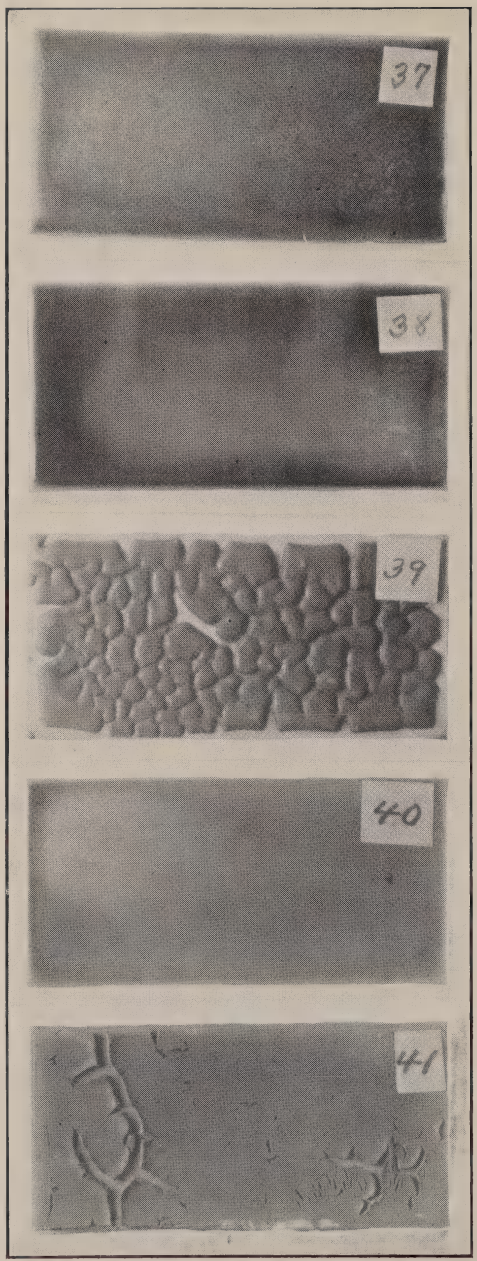
26. *Composition.* 0.10 CuO 0.45 CaO 0.30 BaO, 0.15 MgO.

A dry, imperfectly vitrified substance, shrunken and cracked through to the body, and with edges sharp and rolled upwards somewhat. Color, light blue-green or robin's-egg blue. The absence of green in this color makes the cut show light in tone. No signs of probable utility.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41

Series Fired at Cone 2.

0.20 Al_2O_2 1.60 SiO_2 throughout Series.

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37. *Composition.* 0.10 CuO 0 30 CaO 0.30 K_2O 0.30 Na_2O.

Fairly well fused, obliterating all shrinkage cracks. Covered with a whitish crystalline scum, which destroys the color of the glaze and makes it appear gray in cut. Around edges, the color is an opaque green with a somewhat bluish tint. No utility.

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38. *Composition.* 1.10 CuO 0.30 CaO 0.36 K_2O 0.30 PbO.

A brilliant glossy surface, disfigured by crystalline segregations on right hand lower corner. Oily spots or drops in the glaze, give it a dappled effect by reflected light. This does not show in the cut. Color, a pure dark green, like No. 3. Difference in tint in cut due to drainage and thicker glaze at those points. This glaze is feasible for use, but not as good as No. 3.

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39. *Composition.* 0.10 CuO 0.30 CaO 0.30 K_2O 0.30 BaO.

A shrunken, crackled mass, in which the edges have fused and rounded and the cracks healed over in part. Color is rather dull dark bluish-green, not dissimilar to No. 4, which is similar in composition. Glaze not valuable in its present shape, but offers a good lead for investigation.

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40. *Composition.* 0.10 CuO 0.30 CaO 0.30 K_2O 0.30 ZnO.

A smooth, briliant, glossy glaze, whose surface shows only slight defects in reflected light. Color is very remarkable. Around edges, pale transparent apple-green, showing dark in cut. Then comes a border, one-quarter inch wide, of bright azure blue, semi-transparent and contain fibrous suspended matter, which can be seen in cut. The center is a uniform opaque blue-green or "robin's egg blue." The color seems accidental, and if it could be duplicated might be useful.

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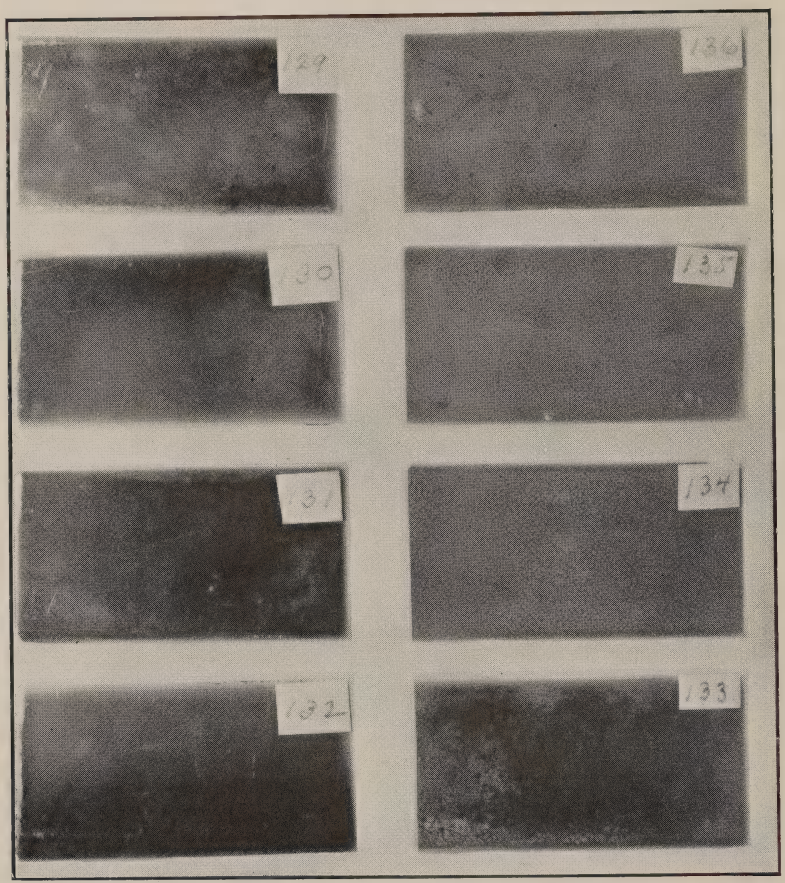
41. *Composition.* 0.10 CuO 0.30 CaO 0.30 K_2O 0.30 Mgo 0.20.

A gray slightly greenish unfused and rough surface with wide shrinkage cracks. No utility.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Series Fired at Cone 2.

Formula

$$\left.\begin{matrix} 0.10\ CuO \\ 0.30\ CaO \\ 0.15\ K_2O \\ 0.30\ CaO \\ 0.15\ ZnO \end{matrix}\right\} x\ Al_2O_3,\quad 1.60\ SiO_2$$

129. $Al_2O_3 = 0.10$
A fine brilliant copper-green glaze, perfectly transparent and free from blemishes, except slight undissolved matter along lower edge.

130. $Al_2O_3 = 0.15$
Same as above, without the undissolved matter.

131. $Al_2O_3 = 0.20$
Darker, yellower green. Glaze was probably dipped heavier than preceding, but color is also different.

132. $Al_2O_3 = 0.25$
About like 131, only the glaze has drained to lower edge, perfectly transparent.

133. $Al_2O_3 = 0.30$
A yellower green, semi-opaque and with a good deal of a whitish segregation around edges and left hand end. The surface still bright shows dark in the cut.

134. $Al_2O_3 = 0.35$
A beautiful matt glaze, smooth as silk, with a delicate whitish dapple mark. This glaze is very promising for general matt purposes.

135. $Al_2O_3 = 0.40$
A somewhat lighter colored but equally beautiful matt glaze, very soft and silky in texture. Dapple marks are much finer, but still distinguished in cut. As good as 134 for use.

136. $Al_2O_3 = 0.45$
A paler green than any. Dapple marks very fine indeed. Glaze is still smooth and perfect for a matt, but the marks of recently healed shrinkage cracks show that the glaze is near its workable limit.